Understanding human behaviour in fire

Kobes, M.

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M. Kobes

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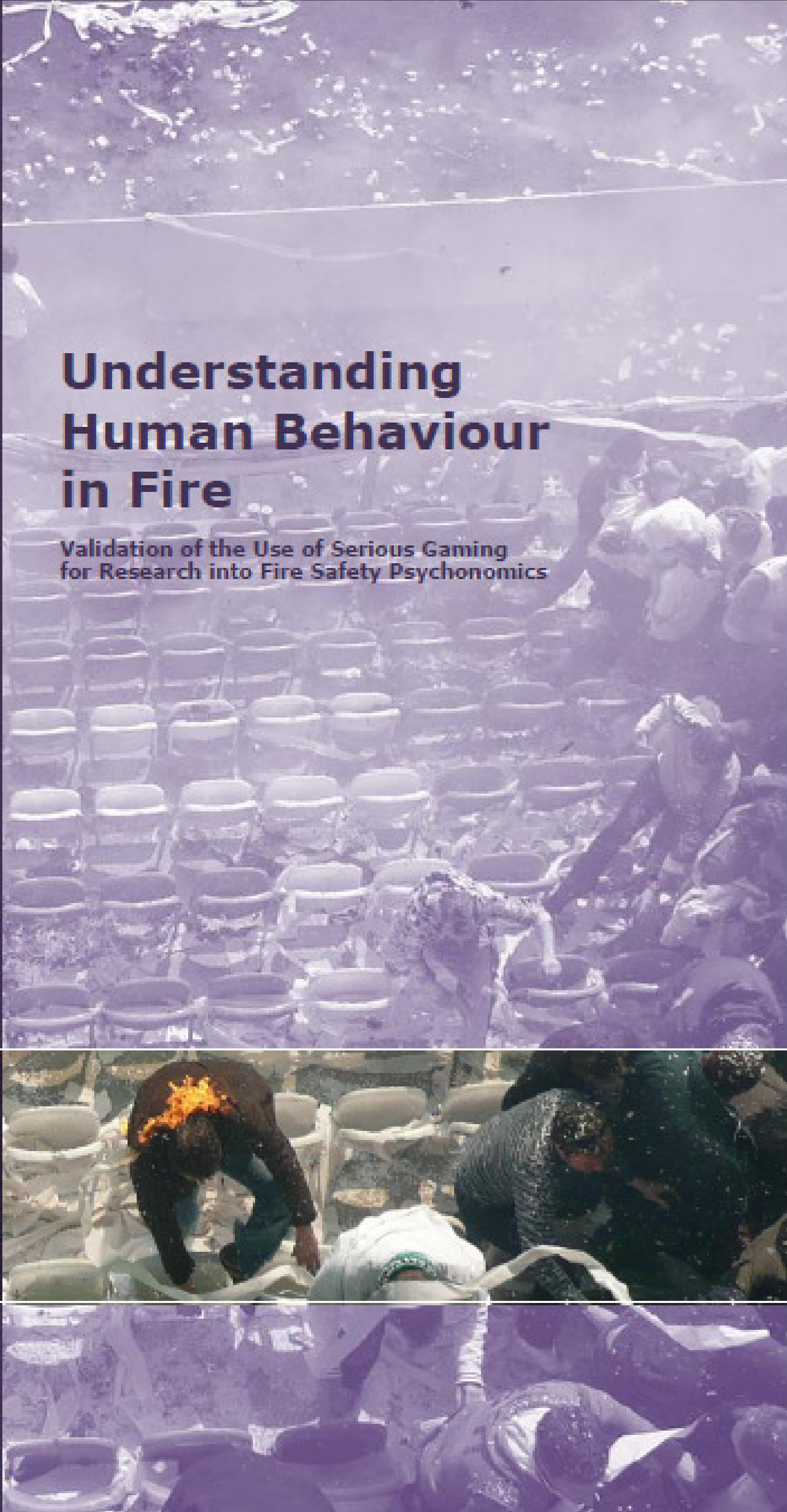

UNDERSTANDING HUMAN BEHAVIOUR IN FIRE

Validation of the Use of Serious Gaming for Research into Fire Safety Psychonomics

Margrethe Kobes

Thesis committee:

Prof.dr. I. Helsloot, VU Amsterdam *promotor*
Prof.dr.ir. B. de Vries, TU Eindhoven *copromotor*
Dr.ir. J.G. Post, Nederlands Instituut Fysieke Veiligheid
Dr. K. Boyce, University of Ulster
Prof.dr. P. van Hees, Lund University
Prof.dr.ir. S.P. Hoogendoorn, TU Delft
Prof.dr. W. Dijkstra, VU Amsterdam

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VRIJE UNIVERSITEIT

UNDERSTANDING HUMAN BEHAVIOUR IN FIRE

Validation of the Use of Serious Gaming for Research into Fire Safety Psychonomics

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad Doctor aan
de Vrije Universiteit Amsterdam,
op gezag van de rector magnificus
prof.dr. L.M. Bouter,
in het openbaar te verdedigen
ten overstaan van de promotiecommissie
van de faculteit der Sociale Wetenschappen
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door

Margrethe Kobes

geboren te Zevenhuizen

promotor: prof.dr. I. Helsloot
copromotor: prof.dr.ir. B. de Vries

Aan mijn ouders

Contents

The Code of Hammurabi is created in ancient Babylon. It was enacted by the sixth Babylonian king, Hammurabi. One nearly complete example of the Code survives today, inscribed on a seven foot, four inch tall diorite stele in the Akkadian language in the cuneiform script.

If a builder builds a house for someone, and does not construct it properly, and the house which he built falls in and kills its owner, then that builder shall be put to death

Code of Hammurabi, article 229 (ca. 1790 BC)

Chapter 1

Introduction

1.1 Fire safety in buildings

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1.2 Psychonomics and fire safety

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1.3 Wayfinding and evacuation behaviour

< This text is not publicly available >

1.4 Objective and scope

The primary aim of this research was the validation of a new research method that uses serious gaming. The new research method consists of an analysis model to systematically study the fire response performance of people in buildings (FRP-model) and of a virtual environment wherein the human behaviour can be comprehensively studied, namely a serious game. The serious game is ADMS-BART, which is the *Behavioural Assessment and Research Tool* (BART) in the existing virtual training tool, the *Advanced Disaster Management Simulator* (ADMS). This serious game has been specifically developed for the adoption of virtual reality in research on human behaviour in fires and fire safety psychonomics. After ADMS-BART is validated as a research tool, a multitude of experiments can be carried out for deciding which building design best fits actual human behaviour during fires.

The new research method has been developed to obtain insight into evacuation behaviour and the effect of building design on that evacuation behaviour, in particular on wayfinding. The additional aims of the research are therefore to (1) obtain insight into human behaviour in fires, particularly the intentions on which the route choice of evacuees are based and (2) study the influence of one or more aspects of human factors, building factors and fire factors on the fire response performance and the wayfinding performance in particular. There are three main reasons for the focus on wayfinding during evacuation:

- There is need for insight into the decision-making processes that evacuees pass through. Some aspects of wayfinding during evacuation and human fire response performance have been investigated; however, they have not been discussed at great length. The way that persons find their escape route and how this process can be supported with layout and design measures has hardly been examined.
- There is need to examine the influence of various building design alterations, as situational surroundings and building features are expected to influence evacuation behaviour.
- Wayfinding itself can pre-eminently be studied in a virtual setting, since building modifications, for example design alterations of the escape route, are easily made within virtual reality.

1.5 Research approach and thesis outline

Several approaches have been used in this research. In this chapter, the research approaches are presented. The overview of research approaches also provides a stepping-stone for the structure of the thesis. The structure of the thesis is organised as shown in Figure 1.2.

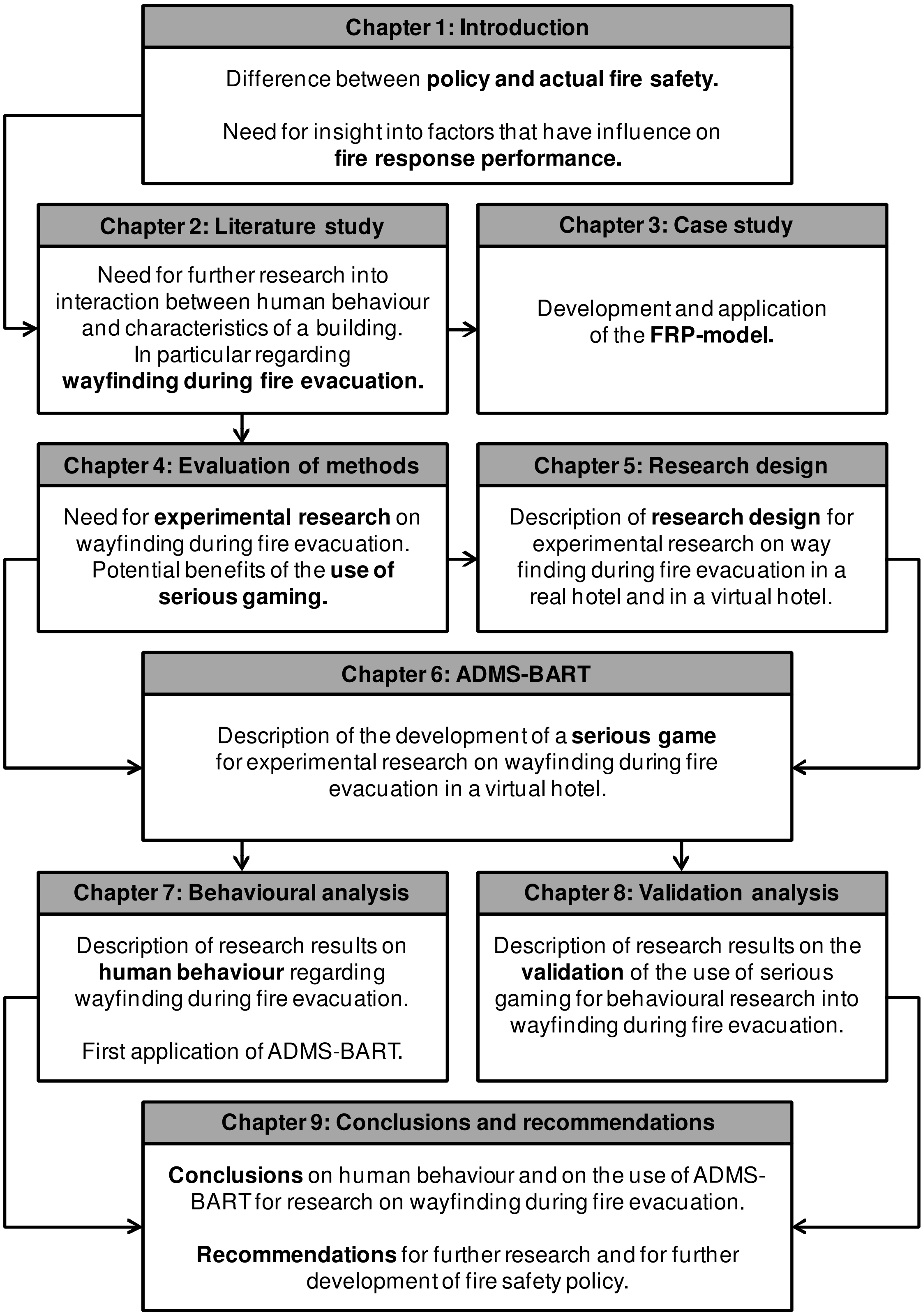

Figure 1.2. Structure of thesis

Introduction
In the introduction (Chapter 1), it has been revealed that the principles and assumptions in current (Dutch) policy are not consistent with the knowledge in the literature. Moreover, there is need for insight into factors that have influence on the fire response performance.

Literature review
To identify the most critical factors that determine the fire response performance of occupants, over one hundred scientific papers have been reviewed. The literature review has resulted in an overview of critical factors that determine the fire response performance of the occupants of a building. The literature review is presented in Chapter 2.

Case study
The overview of critical factors for fire response performance has been put into a model, which is the fire response performance model (FRP-model). To make the model applicable for further research on human behaviour in fire, the model has been modified to a qualitative model. Therefore, the expected influence of the critical factors is determined based on existing literature. Additionally, the application of the qualitative FRP-model as a priori theory for case studies [Yin 1989] on fire safety psychonomics has been verified by conducting a case study on the fire response performance in a fire in a football stadium. The FRP-model and its application in the case study are presented in Chapter 3.

Evaluation of research methods
A case study is not the only possible method for research on fire safety psychonomics. To identify methods for behavioural research and to consider their use for collecting data on fire safety psychonomics, several research methods have been evaluated. The evaluation consists of an analysis of eight key aspects of research and has resulted in an overview of arguments for and against the use of specific research methods to collect data on fire safety psychonomics. Four possible research methods have been analysed, namely the method of experimental research, case studies, the use of simulations and the use of serious games. The evaluation of research methods is presented in Chapter 4.

Methodology
Based on the evaluation of research methods (Chapter 4), two methods of research were found to be most suitable to gain the needed insight into fire safety psychonomics, namely the new method of the use of serious games and the existing method of experimental research in the form of fire drills. The method of fire drills has been scientifically endorsed in research on human behaviour in fire. However, the method of the use of serious gaming in this field of research has not yet been convincingly validated. For the validation of ADMS-BART, the method of fire drills has been used in a real setting as well as in the virtual setting of the serious game. Additionally, a user convenience analysis has been conducted to explore the possible necessities to fine-tune the serious game ADMS-BART during its development. The research designs of the experimental research, the validation analysis and the user convenience analysis are presented in Chapter 5.

Development and validation of ADMS-BART
To adopt the possibilities of virtual reality for studying human behaviour in fires, a new research method has been developed. This new method makes use of the serious game ADMS-BART, which is the *Behavioural Assessment and Research Tool* (BART) in the existing virtual training tool, the *Advanced Disaster Management Simulator* (ADMS). This serious game has been specifically developed for the adoption of virtual reality in research on human behaviour in fires and fire safety psychonomics. The development of ADMS-BART is presented in Chapter 6.

To test whether the serious game ADMS-BART is able to represent a convenient fire situation and to make sensible use of the new research method possible, it has been validated by comparing the results of experiments in the serious game with results of the same experiments in the real world. For the experimental research, a series of unannounced fire drills were carried out in a real setting and in a virtual setting. The experiments in the real setting were conducted in hotel Veluwemeer, located near the Dutch city of Amersfoort. The experiments in the virtual setting were conducted in a replica of hotel Veluwemeer. The findings of the validation are given in Chapter 8.

Experimental research: Analysis on behavioural aspects
The additional aims of the experimental research were to obtain insight into human behaviour in fires, particularly the intentions on

which the route choice of evacuees are based, and to study the influence of one or more aspects of human factors, building factors and fire factors on the fire response performance and the wayfinding performance in particular. To obtain insight into human behaviour in fires and to study the possible influences, the results of the tests in the real and virtual hotel were analysed on behavioural aspects. The results of the behavioural analysis are presented in Chapter 7.

Conclusions and recommendations
The application of the above mentioned research approaches has resulted in conclusions on human behaviour and on the use of ADMS-BART for research on wayfinding during fire evacuation as well as in recommendations for further research and for further development of fire safety policy. A summary of conclusions and recommendations are presented in Chapter 9.

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[Photo by R. Hagen]

The lack of knowledge about fires on the part of building occupants, has a parallel in the misconceptions that fire safety engineers have about people's reactions when faced with a fire

Guylène Proulx (1960-2009)

Chapter 2

Building Safety and Human Behaviour in Fire: A Literature Review

In this chapter, a review of the existing knowledge on building safety and human behaviour in fire is presented. After the Introduction in Section 2.1, an overview of considerable research into human behaviour in a fire is given in Section 2.2. After that, in Section 2.3, the findings in the literature are presented as an overview of the critical factors that determine the fire response performance of the occupants of a building. The conclusions are presented in Section 2.4.

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[Photo of Euroborg stadium fire 2008, by B. Tuitman]

Don’t follow the crowd, take a shortcut

Frido Dido, 7-up mascot

Chapter 3

Fire Response Performance Analysis: A case study

In this chapter the behaviour of supporters in a football stadium fire is analysed by the use of the fire response performance model (FRP model). In Section 3.1 an introduction to the FRP model is presented. In Section 3.2 the FRP model is described in the form of a qualitative analysis model. The application of the FRP model in the case study of a football-stadium fire is presented in Section 3.3. In Section 3.4, a reflection on the response-performance model and its suitability for the evaluation of human behaviour in fire in a building is presented. Conclusions and recommendations are given in Section 3.5.

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[Photo of Enschede firework disaster in 2000, by unknown]

Although nature commences with reason and ends in experience it is necessary for us to do the opposite, that is to commence with experience and from this to proceed to investigate the reason

Leonardo da Vinci (1452-1519)

Chapter 4

Methods for research on building fire safety: An evaluation study

In this chapter several analysis tools for fire safety engineering and several research methods for collecting data on fire safety psychonomics are discussed. A discussion of the analysis tools for fire safety engineering is presented in Section 4.2. In Section 4.3 the discussion four possible research methods for collecting data on fire safety psychonomics is presented. A further analysis of arguments for and against the use of these four methods is presented in Section 4.4. The conclusions are presented in Section 4.5.

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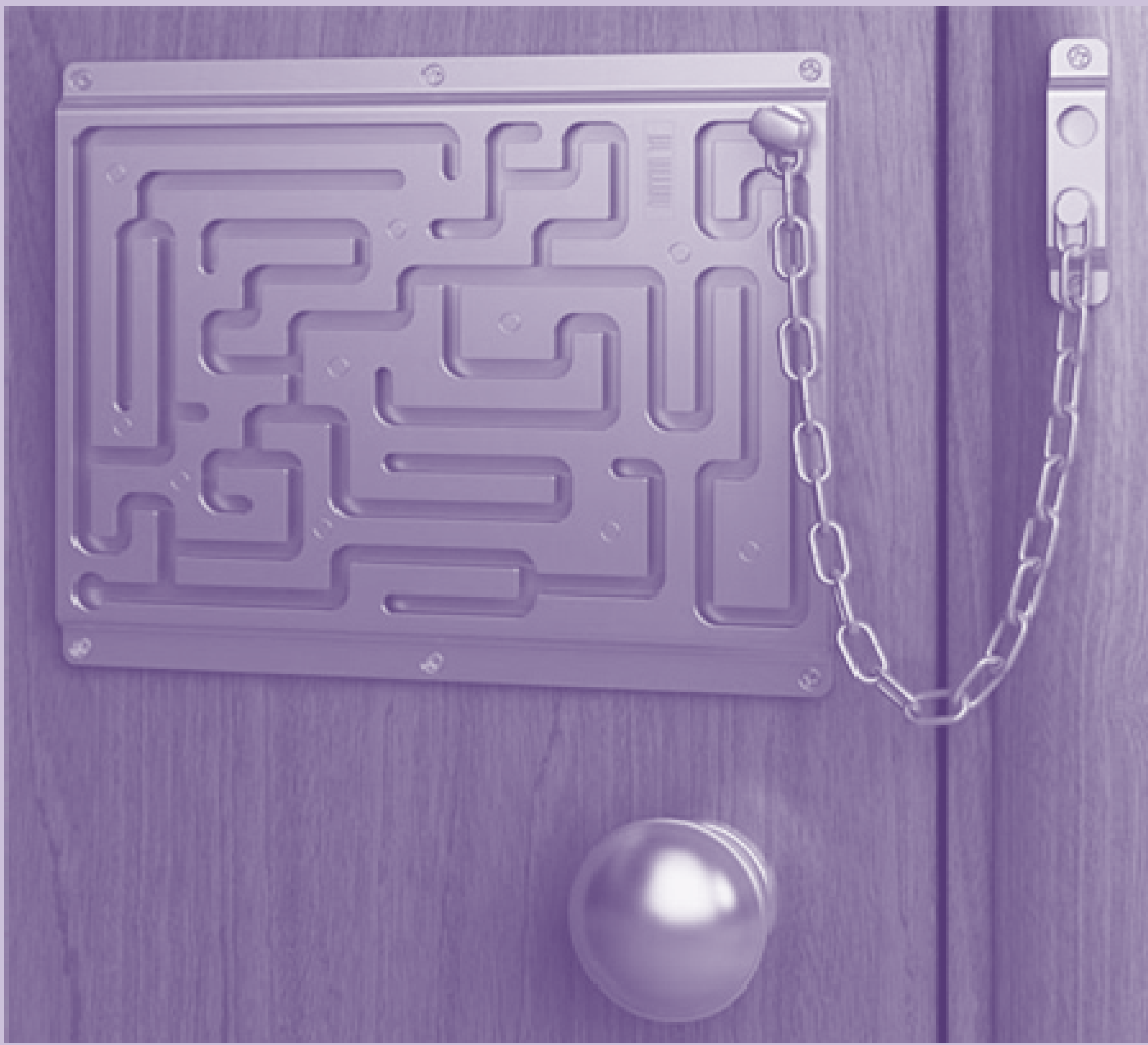


Experience without theory is blind,
but theory without experience
is mere intellectual play

Immanuel Kant (1724-1804)

Chapter 5

Experimental research design

In this chapter, designs are presented for experimental research in a real hotel and in a virtual replica of the hotel in ADMS-BART. The research design of the user convenience analysis and the validation of ADMS-BART are also presented. In Section 5.1, a general introduction to the research design is given. Section 5.2 contains an introduction to the four test scenarios. The three test sessions are described in Section 5.3. The test activities, namely the fake tests, the BART training and the evacuation tests, are presented in Section 5.4. The types of analysis are described in Section 5.5. The research design of the experimental research is presented in Section 5.6, the validation of ADMS-BART is described in Section 5.7, and the scientific foundation of the research design is given in Section 5.8. The methods of data gathering are presented in Section 5.9. In the final section, Section 5.10, details are given regarding the participants and the invitation and compensation for participation.

5.1 Introduction

5.1.1 Scientific foundations of the research design

Information on human behaviour during fires that has been presented in the literature (see Chapter 2) is implemented in the research design. The main findings on human behaviour taken from the existing literature and the connecting experimental principles are given in Table 5.1.

Table 5.1.a. Human behaviour and related experimental principles

No	Main findings on human behaviour	Experiment principles
1.	Most fatal fires occur at night when occupants are asleep [Bruck 2001; Kobes 2008]	In the real hotel, the test persons are sleeping and are awakened by an emergency message.
2.	Spoken emergency messages are taken more seriously by occupants than alarm bells [Pauls 1984; Proulx 2000; Proulx and Laroche 2001; Proulx and Richardson 2002]	The emergency message is a spoken phone message.
3.	In most of the fatal fires, a trained BET was not present [Tubbs 2004; Kobes 2008]	The test persons are tested individually, and no BET official will assist them.
4.	One of the four environmental variables that influence wayfinding performance is plan configuration [Raubal and Egenhofer 1998]	The corridors of the chosen hotel have several bends, side-halls and a dead end.
5.	One of the four environmental variables that influence wayfinding performance is the degree of architectural differentiation [Raubal and Egenhofer 1998]	The layout of the chosen hotel is classified as 'complex'.
6a.	Occupants normally evacuate using familiar routes, mostly the main exit, which is normally the entrance of a building [Graham and Roberts 2000; Sandberg 1997]	The influence of smoke on route choice is investigated in the basic scenario and in the smoke scenario. In the smoke scenario, the route towards the main entrance is blocked by (simulated) smoke. In the basic scenario, there is no smoke visible.
6b.	In numerous fatal fires, the main entrance was blocked by smoke and heat of the fire [Tubbs 2004; Kobes 2008]	
6c.	People tend to evacuate through smoke-filled areas [Frantzich 1994; Gwynne et al. 2001]	

Table 5.1.b. Human behaviour and related experimental principles

No	Main findings on human behaviour	Experiment principles
7.	Experiments have revealed that people experience the illumination level of emergency lighting as very low [Proulx et al. 2000]	The influence of low illumination level on route choice is investigated by comparing the results of the tests in the smoke scenario with the results of the tests in the lighting scenario.
8a.	One of the four environmental variables that influence wayfinding performance is the use of signs [Raubal and Egenhofer 1998]	The influence of two types of signs is investigated in the smoke scenario and in the low exit sign scenario. In the smoke scenario, green exit signs are located at ceiling level; in the low exit sign scenario, they are located at floor level.
8b.	Evacuees appear to be hardly aware of the presence of escape route signs at ceiling level [Ouellette 1993; Johnson 2005]	
8c.	Photoluminescent low-level exit path markings are likely to be more effective than conventional escape route signs [Ouellette 1993; Proulx et al. 2000]	
9.	Personnel directives on route choice appear to have a positive effect on the utilisation of fire exits [Benthorn and Frantzich 1996; Sandberg 1997; Graham and Roberts 2000; Johnson 2005; Kobes 2008]	The functionality of having personnel present in the hotel giving directives on route choice is implemented in ADMS-BART. *However, it is not used in the present research.*
10.	One of the four environmental variables that influence wayfinding performance is visual access [Raubal and Egenhofer 1998]	The functionality of changing the visual access is implemented in ADMS-BART; for example, the location of doors and the transparency level of glass in doors and windows can be changed. *However, it is not used in the present research.*

The main experimental principle is the decision to conduct the experiment in the real-world environment at night. This time was chosen because it has been found that most fatal fires occur at night when occupants are asleep. Thus, the night situation can be considered to represent the highest-risk situation. In order to learn about human behaviour in high-risk situations, we chose to approach the real situation as much as possible in the real world test environment. However, because it is desirable to conduct the tests with the serious game in the most uncomplicated way, the experiments in the virtual environment are conducted at day time.

Another important principle is the choice of possible influencing factors that have been tested in experimental research. For example, it has been found that people tend to use the familiar exit, primarily the main exit, even when the route towards such an exit is blocked by smoke. Therefore, the influence of smoke is investigated in the experimental research, by blocking the route towards the main exit. Further details on the foundations of the experimental principles are presented in Table 5.1.

5.1.2 Overview of research activities

The experimental research consists of three main trajectories, namely, test sessions with BARTtrial, test sessions in a real hotel and test sessions with ADMS-BART. Figure 5.1 shows an overview of the research activities.

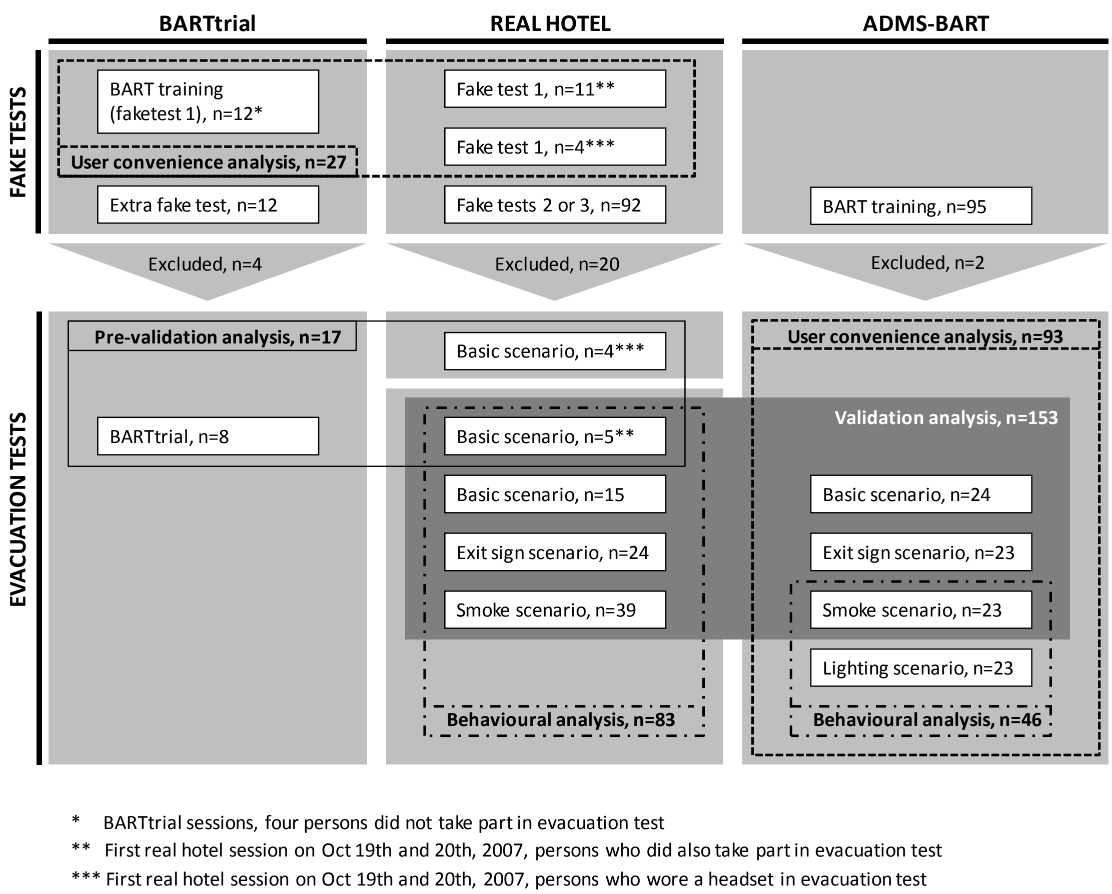


Figure 5.1. Overview of research activities

In each trajectory, two types of test are conducted, namely, so-called 'fake tests' and evacuation tests (see Sections 5.4.1 and 5.4.3). The tests are carried out under four conditions: the basic scenario, the smoke scenario, the low exit sign scenario and the reduced lighting scenario. The results of the tests are analysed with respect to several aspects during various phases of the research and development process. The types of analysis are the user convenience analyses of BARTtrial and ADMS-BART, the behavioural analysis, the pre-validation analysis and the validation analysis.

5.2 Test scenarios

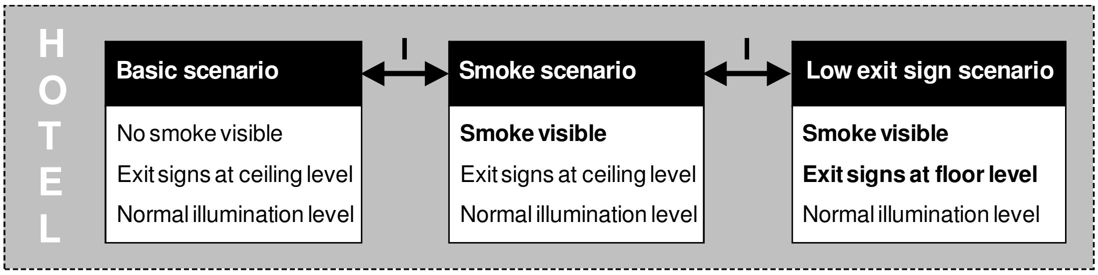
A behavioural analysis is carried out in order to investigate the influence of environmental conditions and building design on human fire response performance. The research consists of experiments carried out under various conditions and in various settings. These settings are labelled 'scenarios'.

To analyse possible influences on human fire response performance, tests are conducted in four settings (see Figures 5.3 and 5.4). In the first scenario, nothing is changed in the hotel setting and is called the 'basic scenario'. In the second scenario, a fire is simulated by smoke pouring out of a hotel room into the corridor and is called the 'smoke scenario'. In the third scenario, a fire is simulated; also, the green exit signs are placed at floor level instead of at ceiling level. This is called the 'low exit sign scenario'. The signs in the low exit sign scenario are placed at about 30 centimetres height above the floor and in front of every set of two hotel room doors. Therefore, there are more signs present in this scenario than in the other two scenarios. In the fourth scenario, a fire is simulated and the illumination level is reduced to emergency level (approximately 1 lux) and is called the 'reduced lighting scenario'.

Impressions of the basic scenario, the smoke scenario and the low exit sign scenario in the real environment are given in Figure 5.2, and a description of the behavioural analysis is presented in Section 5.5. The critical factors of the fire response performance model are implemented in the test scenarios; see Tables 5.2 and 5.3.

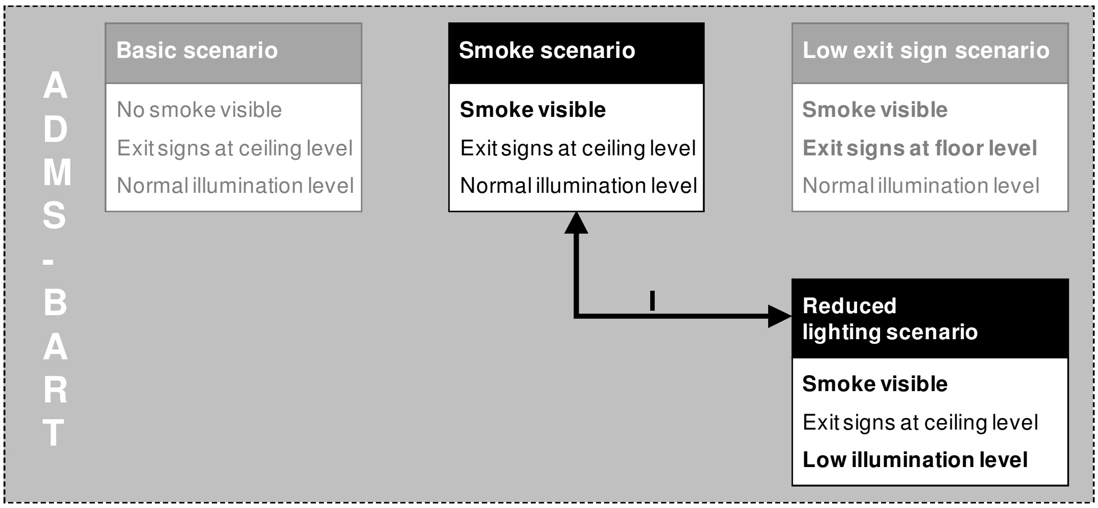
Basic scenario | Smoke scenario | Low exit sign scenario

Figure 5.2. Impression of scenarios in real environment



I = Influence analysis

Figure 5.3. Experiment scenarios in real environment (RE)



I = Influence analysis

Figure 5.4. Experiment scenarios in the virtual environment (VE)

Table 5.2. Building features

Item	Description	RE/VE	Variable or fixed
Layout	Participants on first floor level	RE+VE	Fixed: start location
	Location of exit signs	RE+VE	Variable: ceiling or floor level
Installations	Lighting illumination level	RE	Fixed: normal
		VE	Variable: normal or emergency
Materials	N/A		
Compartmentation	Doors in corridors closed, except for four cases in first two sessions	RE	Fixed: present
	Doors in corridors closed	VE	
Size of building	N/A		
Focus point	N/A		
Occupant density	Maximum of 11 participants in the test area	RE+VE	Fixed: low
Ease of wayfinding	Several intersections	RE+VE	Fixed: medium
Building evacuation team	Not present (in test setting)	RE+VE	Fixed: not present
Maintenance	Adequate	RE+VE	Fixed: adequate

Table 5.3. Fire features

Item	Description	RE/VE	Variable or fixed
Visual features	No smoke visible in basic scenario	RE+VE	Variable: perceptible or not perceptible
	Smoke visible in other scenarios		
Smelling features	No odour in basic scenario	RE	Variable: perceptible or not perceptible
	Slight odour in other scenarios		
	No odour	VE	Fixed: not perceptible
Audible features	No audio	RE	Fixed: not perceptible
	Fire audio	VE	Variable during test
Tangible features	No tangible fire signals	RE+VE	Fixed: not perceptible
Fire growth rate	Controlled smoke layer	RE+VE	Fixed: slow
Smoke yield	No limited sight in basic scenario	RE+VE	Variable: not present or high
	Limited sight in other scenarios		
Toxicity of smoke	Not toxic	RE+VE	Fixed: not present
Heat	No heat	RE+VE	Fixed: not present

In the smoke and low exit sign scenarios in the real environment, the smoke is obtained using a smoke generator. The smoke generator is placed in room 103 (see also Figure 5.7) and produced cold artificial smoke. Before every evacuation test, two members of the research team open the door of room 103 and pour smoke into the corridor. The smoke flow is directed toward room 101 in order to block the route to the main exit and reception desk with smoke that generate limited sight. The smoke moves slowly into the corridor (see Figure 5.2), while the test coordinator alarms the test person. Despite the effort that will be taken to obtain the same level of smoke yield per test case, there will possibly be some slight differences in the level of smoke yield in different tests.

In the smoke and low exit sign scenarios in the virtual environment, a fire is simulated in room 103 by starting a prefixed fire and smoke development scenario. At the moment of the start of the evacuation tests, the level of simulated smoke is comparable to the level of smoke in the test cases in the real environment. As the smoke yield develops in time, there will be a slight difference in the level of smoke yield per case: the longer the participant waits to start to move, the higher the level of smoke yield will be.

5.3 Test sessions

Three types of test sessions are conducted, namely the test sessions with BARTtrial, the test sessions in a real hotel and the test sessions with ADMS-BART.

5.3.1 BARTtrial sessions

The test sessions with BARTtrial are conducted for the development of ADMS-BART and to gain experience in the processes related to the experimental research. Therefore, the test sessions with BARTtrial are essentially similar to those in the real hotel and with ADMS-BART.

Because the participants in the real hotel are to be awakened during the night, the evacuation tests with BARTtrial are conducted during the night, between approximately 02:15-06:45 AM, while the test persons are sleeping in their hotel rooms. There are three major differences compared to the tests in the real hotel:

- The test sessions are not conducted at the location of the sessions in the real hotel, but instead at the NIFV facility, which also has a hotel section.
- The participants are guided from their hotel room to the BARTtrial test room to conduct their evacuation in the virtual hotel.
- The alarm message is not given in the telephone call. Instead, in the telephone call, the test person is asked to come to the test room as soon as possible. When the test person is in the test room and stands in front of the projection screen, the researcher verbally delivers the alarm message (see Section 5.4.3).

Because the participants in the BARTtrial sessions must be trained in using the serious game, the sessions with BARTtrial include a training session. In addition, the participants in the BARTtrial sessions are diverted from the 'evacuation test' by conducting a 'fake test' in the evening before the evacuation test at night. The design of the fake test is such that the participants do not expect, or do not truly expect, a fire drill during the night. This design is also true for the tests with ADMS-BART, though there are two major differences compared to the tests with BARTtrial:

- The training session that is conducted in the first session in the real hotel is labelled 'fake test 1' (see Figure 5.1). Fake test 1 is designed as a user convenience test (for more details, see text under *'user convenience analysis').*
- The participants undergo the real test in BARTtrial at night, after being awakened. The participants in the ADMS-BART sessions perform the evacuation test in the virtual hotel during the daytime.

The set-up of the BARTtrial sessions is presented in Table 5.4.

Table 5.4. Set-up of BARTtrial sessions

Session number	Date	Fake test	Test scenario	Number of participants	Number of successful evacuation tests
T-1	Aug 29th, 2007	1+2	Basic	4	3
T-2	Dec 4th, 2007	1	Basic	5	5
T-3	Dec 5th, 2007	1	Basic	3	

The BARTtrial sessions have been carried out three times. The first two sessions were conducted in the evening and at night; the third session was conducted during the daytime. A total of 12 persons participated in the BARTtrial sessions. In the first session (T-1), four persons participated in fake test 1, fake test 2 and in the basic scenario of the evacuation test. In sessions T-2 and T-3, five and three persons, respectively, participated in fake test 1 and in the basic scenario of the evacuation test. The results of the evacuation tests of the eight participants in T-1 and T-2 are analysed in the pre-validation analysis.

5.3.2 Sessions in the real hotel

The sessions in the real hotel are conducted in hotel Veluwemeer. For a detailed description of the selected object of the experimental research, see Section 5.6.1. During the sessions, several individual fire drills are conducted in which data is obtained on evacuation behaviour in a real environment. The main objective of the sessions in the real hotel is to acquire the data needed for the validation of the use of serious gaming as a research tool. The serious game used in the experimental research is ADMS-BART; using this game, the same type of data on evacuation behaviour is gained, though in a virtual environment. The second objective of the sessions in the real hotel is to gain insight into human behaviour regarding wayfinding during fire evacuation, as the method of fire drills in buildings is widely accepted and endorsed on scientific grounds. The setup of the sessions in the real hotel is presented in Table 5.5.

A session in the real hotel begins in the evening and ends the next morning. The evacuation tests are conducted at night, though the participants are informed only of the 'fake test' that was conducted in the evening. For a detailed description of the sessions in the real hotel, see Section 5.6.3. A total of 107 persons have participated in a total of twelve sessions.

In the first two sessions (RE-1 and RE-2), eight and seven persons, respectively, participated in fake test 1. Eight of these fifteen persons successfully accomplished the basic scenario of the evacuation test. The results of the eight evacuation tests are used in the pre-validation analysis. Because four persons wore a headset camera, the results of their tests are excluded from the behavioural analysis and the validation analysis. Also, another 20 persons did not accomplish the evacuation test successfully and were excluded from the analyses. For details of the reasons for excluding the 24 persons, see Section 5.9.2. A total of 83 test results are used for the behavioural analysis, as well as for the validation analysis.

Table 5.5. Set up of sessions in the real hotel

Session number	Date	Fake test	Test scenario	Number of participants	Number of successful evacuation tests
RE-1	Oct 19th, 2007	1	Basic*	8**	3 (+4**)
RE-2	Oct 20th, 2007	1	Basic*	7	1
RE-3	March 8th, 2008	3	Basic	7	6
RE-4	March 28th, 2008	3	Smoke	12	9
RE-5	March 29th, 2008	3	Smoke	6	6
RE-6	May 16th, 2008	4	Smoke	9	8
RE-7	May 23rd, 2008	4	Smoke	8	6
RE-8	May 24th, 2008	4	Smoke	10	10
RE-9	May 25th, 2008	4	Basic	7	6
RE-10	June 27th, 2008	4	Exit sign	11	11
RE-11	June 28th, 2008	4	Exit sign	10	7
RE-12	June 29th, 2008	4	Exit sign	6	6
			Basic	4	4
			Total**	**107**	**83**

* In some night sessions, the doors in the corridors stood open. In other night sessions, the doors were closed. The results of Phi test show that this factor had no influence on the exit choice (p=0.395).

** Four persons wore a headset camera in order to make a movie of wayfinding behaviour from the participants' perspective. The results of the evacuation test are analysed in the pre-validation analysis, though they are excluded from the behavioural analysis and the validation analysis.

5.3.3 ADMS-BART sessions

The ADMS-BART sessions are conducted using the serious game ADMS-BART. A detailed description of the serious game is presented in Chapter 6. A replica of the real hotel is visualised in the game's virtual environment, and several individual fire drills are conducted in this environment. The main objective of the ADMS-BART sessions is to gain data needed for the validation of the use of serious gaming as a research tool. The second objective of the initial application of ADMS-BART as a research tool is to gain data on human behaviour regarding wayfinding during fire evacuation. The setup of the sessions using ADMS-BART is presented in Table 5.6.

Table 5.6. Set up of sessions with ADMS-BART

Session number	Date (Oct 2008)	Time period	Number of participants	Number of successful evacuation tests
VE-1	17th	09.00-12.00 hrs	12	12
VE-2	17th	18.00-21.00 hrs	18	18
VE-3	18th	18.00-21.00 hrs	24	24
VE-4	20th	09.00-12.00 hrs	7	6
VE-5	20th	18.00-21.00 hrs	25	24
VE-6	23rd	09.00-12.00 hrs	9	9
		Total	**95**	**93**

The sessions with ADMS-BART were conducted during three mornings and three evenings. A session consists of a BART training and an evacuation test. A total of 95 persons participated in the BART training and evacuation tests, though only 93 completed the evacuation tests successfully. A detailed description of the sessions with ADMS-BART is presented in chapter 5.6.3.

5.4 Test activities

Three types of test activities can be distinguished, namely, conducting a fake test, performing a BART training and conducting an evacuation test.

5.4.1 Fake tests

The fake tests consisted of a group exercise and an individual test. The fake tests varied at each session. A short description of the fake tests is given in Table 5.7.

Table 5.7. Description of fake tests

Number	Description
F-1	BARTtrial exercise in group, individual time test in BARTtrial
F-2	Group discussion on risk perception and fire extinguisher demonstration
F-3a+b	a) A guided tour in hotel in small groups, assessment of similarity between real hotel and virtual hotel in BARTtrial, and b) an individual test on accident perception and reaction in NIFV-ADMS
F-4a+b	a) A short presentation of ADMS-BART to the group and b) an individual test on accident perception and reaction in NIFV-ADMS

Fake test 1 was carried out by 27 persons, 12 in the BARTtrial sessions and 15 in the first two sessions in the real hotel. The results of the first part of the fake test, the BARTtrial exercise, are used in the user convenience analysis. Fake test 2 is conducted only in the first BARTtrial session, in which three participants successfully accomplished an evacuation test. The results of these evacuation tests are not included in the behavioural analysis or in the validation analysis. Fake test 3 is conducted in three sessions in the real hotel. A total of 21 participants who conducted fake test 3 successfully accomplished an evacuation test. Six of them conducted the basic scenario of the evacuation test and 15 participated in the smoke scenario. A total of 50 persons who successfully accomplished an evacuation test participated in fake test 4. Ten of them conducted the basic scenario of the evacuation test, 16 conducted the smoke scenario and 24 completed the low exit sign scenario. A full description of the four fake tests is presented below.

Fake test 1: BARTtrial exercise

The first fake test was conducted in order to gain information to be used in the further development of ADMS-BART. The tests were conducted with BARTtrial and are designed 'user convenience tests'. The test consisted of a series of five exercises in BARTtrial. The first three were conducted behind a laptop screen with three types of controlling devices, namely, a joystick, a gamepad and a keyboard with mouse. After these exercises, the participant was asked to fill in a post-test questionnaire that included questions about his or her preference of controlling device. The following two exercises were conducted with two (additional) types of projection, namely, on a small screen or on a large screen. Following these two exercises, the participant was asked to fill in a second post-test questionnaire that included questions about his or her preference of projection screen size. The results of the enquiry with BARTtrial are presented in Section 6.4. In the individual time test in BARTtrial, the participant was located in one of the virtual hotel rooms and was asked to get out as quickly as possible. The time test was presented to the participant as the final test. At the end of the evening session, the results of the preferences questionnaire and the time tests were presented to the group of participants.

Fake test 3a: Guided tour and face validity test

The group of participants was divided into several small groups. These small groups were taken one at a time on a guided tour through the hotel, walking from the reception desk to the hotel room wing and back to the reception desk. After the guided tour, the participants were shown the same route in the virtual hotel in ADMS-BART. After they had seen the tour in the virtual hotel, the participants were asked to fill in a form with questions on the level of comparison of several building aspects. They were instructed to mention any differences they perceived in the features of the virtual hotel compared to those of the real hotel. At the end of the evening session, the results of the face validity test were presented to the group of participants.

Fake test 4a: Presentation of ADMS-BART

Because the development of the serious game was completed after the fifth experimental session, fake tests 1 and 2a were no longer needed. However, it was necessary to give the participants a plausible reason for the need to stay overnight in the hotel. Therefore, the participants were shown the route from the entrance to the hotel rooms in the virtual hotel and were told that a short group test in the virtual hotel would take place the next morning at 10:00 AM.

Fake test 3b / 4b: Individual test in NIFV-ADMS

The individual test in NIFV-ADMS was conducted so that it would have no influence on the night experiment. Therefore, the test did only include questions on civil help reaction in case of a car fire and did not include any question on evacuation, wayfinding, or fire in a building. The scenario of the individual test was a car crash with two cars at a crossroad in a virtual town. In the near surroundings, a fuel filling station was present. One of the two cars on the crossroad caught fire and after approximately one minute an explosion occurred, evidenced by a loud bang and the rapid development of visible flames. The participant was asked to speak out loud during the test and tell about their perception of the situation, their thoughts and about the actions that they would take. At the end of the evening session, the results of the individual tests in NIFV-ADMS were presented to the group of participants.

5.4.2 BART training

The BART training in the sessions with ADMS-BART consisted of an exercise in ADMS-BART. The exercise scenario was a daytime environment with normal lighting, no fire or smoke present and exit signs placed at high levels. In the exercise, the participant was to imagine that he or she arrived at the hotel, checked in and walked to their room. Afterwards, the participant had to walk to the restaurant, located near the reception desk, and walk back to his or her room. The participant was then free to move around as he or she would when in a real hotel. The first purpose of the exercise was for the participant to become familiar with the controlling device. The second purpose was for the participant to become familiar with the environment. To achieve an approximately equivalent level of familiarity with the hotel layout to that of the participants in the real hotel, the participants in the ADMS-BART sessions were required to walk the same routes in the training exercises as many times as the participants in the real hotel had walked them. The training sessions required approximately half an hour to a maximum of one hour per individual.

5.4.3 Evacuation tests

The evacuation test consisted of an individual fire drill. The starting point of the evacuation test is a hotel room (see Figure 5.3). In the sessions in the real hotel, the participant is physically located in the room. In the sessions with ADMS-BART, the participant stands in front of a screen on which a visualisation of the virtual hotel room is projected. The evacuation tests in the real hotel are conducted at night, when the participant is asleep. The evacuation test in the virtual hotel is conducted in the morning or in the evening, though the situation was described to the participant as a night situation in a hotel in which the participant would be asleep in his/her hotel room. The hotel room in the evacuation test was the same as the one the participant had used in the training session. The evacuation test began with a spoken fire alarm. In the literature, it is found that a fire alarm using a spoken message, or a communication system using personnel directives, is taken most seriously by the occupants of a building [Proulx & Richardson

2002; Pauls 1984; Proulx 2000]. Therefore, the test persons were alarmed with the message:

"This is the receptionist speaking. There is a mention of fire on your floor. Leave the hotel as quickly as possible. Other guests are also receiving this alarm. I repeat: This is the receptionist speaking. There is a mention of fire on your floor. Leave the hotel as quickly as possible. Other guests are also receiving this alarm."

In the real hotel, the message was given by means of a telephone call because another communication system for spoken messages was not installed in the hotel. Another reason for the use of a telephone call is the possibility of alarming the participants individually. The individual alarm was required, as the evacuation test was intended to be an individual fire drill. When the participant opened the hotel room door and entered the corridor, he or she was confronted with the situation of a test scenario. A description of the test scenarios is presented in Section 5.2. At the moment at which the participant reached the reception desk or opened the fire exit, the evacuation test was ended. After the evacuation test, the participant completed a questionnaire.

5.5 Types of analyses

The results of the tests are used in four types of analyses, namely in the user convenience analysis, the behavioural analysis, the pre-validation analysis and in the validation analysis.

5.5.1 User convenience analysis

Two user convenience analyses are conducted, one with BARTtrial and one with ADMS-BART. The results of the two analyses are presented in Chapter 6.

The main motive for conducting the user convenience test with BARTtrial is to explore the possible necessity of fine-tuning the serious game ADMS-BART during its development. A secondary motive is to gain experience with the process of training participants to use the serious game. The user convenience tests with BARTtrial consist of a series of exercises in BARTtrial after which a questionnaire is completed. The user convenience tests are conducted in the two BARTtrial sessions and in the first two sessions in the real hotel (see also Tables 5.1 and 5.2). In total, 27 participants have completed the user convenience tests with BARTtrial.

The motives for conducting the user convenience test with ADMS-BART are to obtain a picture of the participants' perception of the simulated environment, to explore the user-friendliness of the serious game and to characterise the target group in terms of their level of gaming experience and age. The user convenience test with ADMS-BART is part of the evacuation test because it consists of the training session and the evacuation exercise with ADMS-BART, after which a questionnaire must be completed. The questionnaire for the user convenience analysis is therefore incorporated into the post-test questionnaire (see Section 5.9.4) of the ADMS-BART sessions. The user convenience tests are conducted in all of the ADMS-BART sessions (see also Figure 5.1). In total 93, participants have completed the user convenience tests with ADMS-BART.

5.5.2 Behavioural analysis

The primary aim of the research is the validation of a new research method that uses serious gaming. The new research method has been developed to generate specific information that fire safety engineers need in order to design safe buildings that comply with actual human behaviour in fires. An additional aim of the research is therefore to obtain insight into human behaviour in fires, particularly into the intentions on which the route choices of evacuees are based and to study the influence of human factors, building factors and fire factors on fire response performance and wayfinding performance in particular.

To obtain insight into human behaviour during fires and to study possible influences of fire on this behaviour, the behavioural aspects of the results of the tests have been analysed. The tests in the three scenarios in the sessions in the real hotel are analysed in detail, as the use of fire drills in a real building is a scientifically-endorsed method of behavioural analysis. In the sessions with ADMS-BART, only the additional tests in the lighting scenario and the comparison with the results of the tests in the smoke scenario are analysed in detail, because the validation of ADMS-BART was the main motive for the tests in the virtual environment. The possible influences of the surroundings are tested in both environments. The results of the behavioural analysis are presented in Chapter 7.

The possible influence of environmental conditions (smoke or no smoke) and of the location of exit signs (high-placed or low-placed) on human fire performance are tested in both the real and the virtual environment. In order to do this test, the results obtained using the smoke scenario are compared to those obtained using the basic scenario or the low exit sign scenario (see 'I' in Figure 5.5). In the low exit sign scenario in the real environment, the low-placed exit signs were already installed before the participants first entered the hotel wing.

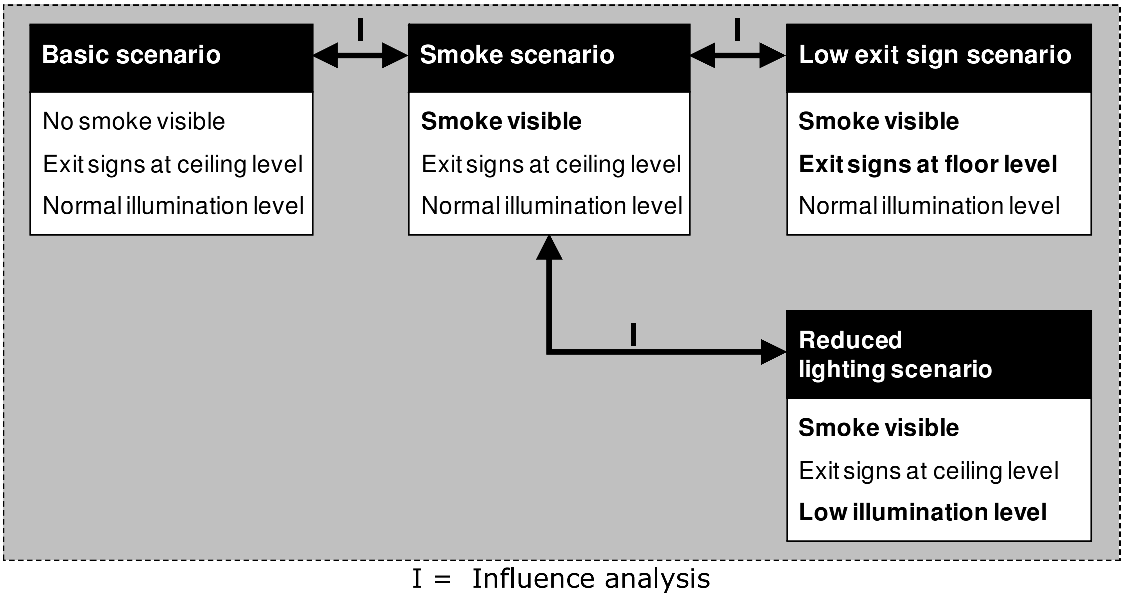


Figure 5.5. Experiment scenarios for behavioural analysis

In the virtual environment, a third aspect, namely the influence of the illumination level (normal or low), is also tested. Therefore, the results of the reduced lighting scenario are compared with those of the smoke scenario. In the smoke scenario, a fire is simulated by smoke pouring out of a hotel room into the corridor. In the 'reduced lighting scenario', the illumination level is reduced to emergency level (approximately 1 lux) and smoke is poured into the corridor.

5.5.3 Pre-validation and validation analysis

To adopt the possibilities of virtual reality for studying human behaviour in fires, a new research method has been developed. This new method makes use of the serious game ADMS-BART. To test whether this game can represent a realistic fire situation and to make possible sensible use of the new research method, the game was validated by comparing the results of experiments conducted using the serious game with results of the same experiments in the real world. The findings of the validation analysis are given in Chapter 8.

Prior to the validation of ADMS-BART a pre-validation analysis was conducted in order to investigate the potential validity of BART. In the pre-validation analysis the results of the tests in BARTtrial were compared to the results of the tests in the first two sessions in the real hotel. The tests in both BARTtrial and in the real hotel were conducted during the night, because the tests in BARTtrial were also conducted as a try-out for the coordination and execution of the evening and night sessions in the real hotel. The quantity of the cases (n=8 and n=9) in the pre-validation tests was too low for a acceptable validation of BARTtrial. Nevertheless, the results of the primary validation analysis indicated that wayfinding tests in BART are most likely to give corresponding results with the same tests in the real hotel [Kobes et al. 2010]. Furthermore, it is found that in BARTtrial as well in the real hotel about half of the participants did not walk the shortest route. There are also no major differences in the scores for the assessed emotions, such as in the experienced sense of emergency, sense of time pressure, or ease of wayfinding.

5.6 Design of the experimental research

5.6.1 Selected object

A hotel building is selected as the object for closer research on human behaviour in fires. In the Netherlands, thousands of hotel buildings are present and millions of individuals make use of hotel accommodations annually. Moreover, evaluations of fatal fires reveal that, in the Netherlands, the major fatal fires have mostly occurred at night in residential and public buildings [Kobes 2008]. Hotel accommodations, in particular, have a high risk profile; besides the aspect of being asleep at night, the majority of hotel guests are also not familiar with the building and the escape routes. Consequently, the hotel guests are partly dependent on a Building Evacuation Team (BET) in case of emergency. Incident evaluations have revealed that, in most fatal fires, a well-trained BET was not present [Kobes 2008]. For these reasons, the experiments used in this study are unannounced fire drills in a hotel at night. Figure 5.6 shows a map of the hotel Veluwemeer and Figure 5.7 shows the location of the hotel rooms in the test environment.

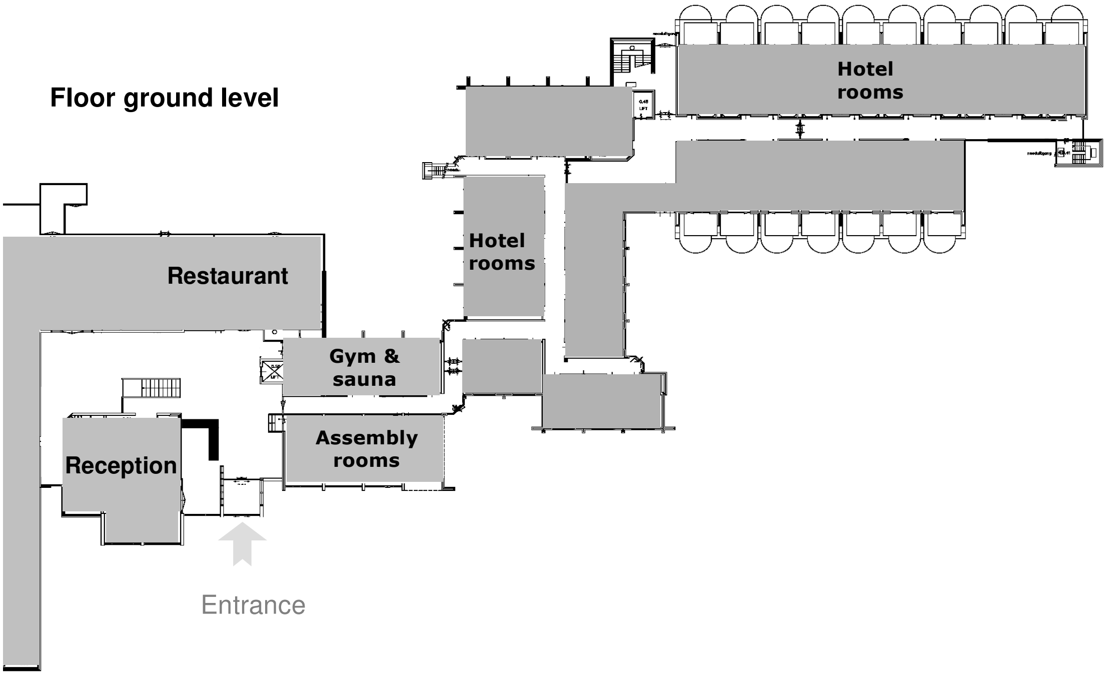


Figure 5.6. Map of hotel Veluwemeer

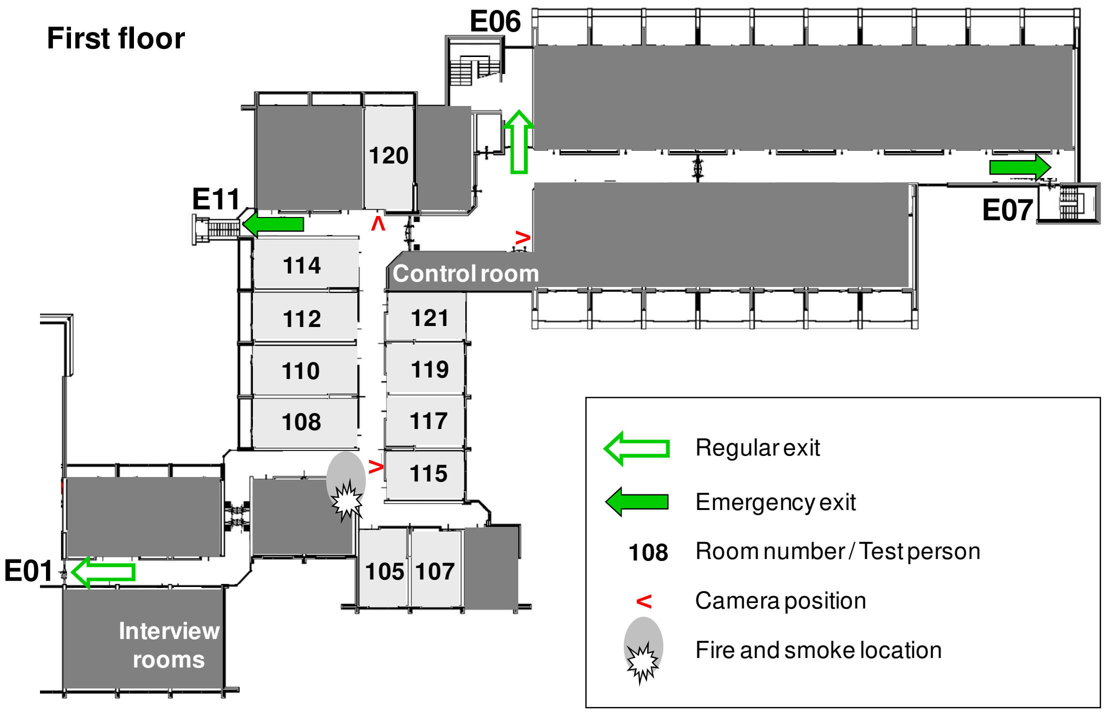


Figure 5.7. Floor plan of test environment

The hotel rooms used in the experimental research are located on the first floor. The floor plan of the first floor is comparable to that of the ground floor. Figure 5.8 gives an impression of the building design in the vicinity of the hotel rooms that are used in the experiments.

Towards main exit (E01) | Towards nearest fire exit (E11) | Towards fire exit (E06)

Figure 5.8. Impressions of building design

For ethical reasons, the participants were made aware that they were involved in research on fire safety, though they did not know that they would participate in a fire drill at night. It is, therefore, possibly more precise to describe the experiments as 'partially unannounced fire drills'. Furthermore, the test persons were required to evacuate individually, with no assistance of from BET officials.

5.6.2 Procedures and research teams

General procedures

An ethical commission of the University of Groningen approved the research setup. Before the tests, each participant signed an informed consent form. In the form, it is explained that the tests relate to fire safety and that they can take place at any time of day, either in a virtual reality setting or in real life. Furthermore, the test subjects are informed that the tests are not dangerous and that they are allowed to stop the test at any time. Finally, it is recorded in the form that the test will be videotaped. Additionally, participants were required to complete and sign a health form, in which questions were posed on their visual abilities, possible heart and breathing problems and other health information. The NIFV has concluded a special insurance contract to protect the participants in case of any harm or inconvenience.

Based on the information in the assigned health form (see Section 5.8.4), individual persons were or were not invited to participate in the test. Only apparently healthy persons were chosen to be test participants. Furthermore, the selection of participants was based on medical approval by a qualified nurse. Persons who suffer from specific health problems, such as heart problems, epilepsy, asthma, carsickness and limited sight, were excluded.

Additional procedures for experiments in the real environment
Several additional safety procedures have been followed in order to prevent the occurrence of accidents during the experimental sessions. A safety document outlining these procedures has been drawn up. One of the procedures was to inform the local fire service and the regional emergency room before the start of the night time experimental session. In such cases, the test coordinator called the emergency room to inform them that the automatic fire alarm would be temporarily inactivated. In case of an actual emergency, the test coordinator would call the emergency room and the operator would know that the call had to be taken seriously and would immediately warn the fire brigade.

Another procedure involved conducting a safety briefing before every experimental session, as the composition of the research team varied in different sessions. In the briefing, the research team was instructed in proper safety procedures and briefed on the special tasks to be carried out if something were to go wrong. The safety instructions were also provided in written form in a handout that was given to each research member the evening before the experimental session. The research team consisted of at least one educated and trained BET and First Aid member. In case of emergency, this person would take the lead. Safety wardens were required to check that the participants did not try to evacuate via the hotel room windows and to take care of the participants after they opened the fire exit and guide them to the interview rooms. During the evacuation tests, two safety wardens stood outside the hotel near the two nearest fire exits, in positions from which they were able to see the windows of the even-numbered hotel rooms 108 to 120. From the window in the control room, the test coordinator was able to see the windows of the odd-numbered rooms 115 to 121. In case of emergency, the safety wardens were required to warn the test coordinator by means of a two-way radio; if possible, the safety warden was to take the first action. The editor had a real-time view of the corridors by means of video cameras. In case of any inconvenience or irregularity, he would warn the test coordinator. Following a warning from the safety warden or after the occurrence of any inconvenience in the corridors, the test coordinator would stop the test immediately by using the agreements in the 'no-play procedure'. The test coordinator could also intervene in case of emergency.

Research team for the experiments in the real environment
The research team conducting the experiments in the real environment consisted of a total of 11 members; four members were responsible for the fake tests in the evening session and seven members conducted the tests in the night session. The night session was coordinated by the test coordinator, who was located in the control room. The control room was actually the linen room of the hotel. Another research team member, the editor, was located behind a control desk (see Figure 5.9).

The editor had a real-time view of the corridors of the hotel wing where the experiment took place. He videotaped the evacuation test and edited the video immediately after the test so that it could be shown to the participant by one of the two interviewers in the interview room. The test coordinator called the participants during the night and communicated with the other three research team members, the two safety wardens and the receptionist by means of a two-way radio.

Figure 5.9. Control desk

Research team for the experiments in the virtual environment
The research team for the experiments in the virtual environment consisted of a total of six members. The test session was coordinated by the test coordinator, who was located behind a control desk in the training room. A trainer was also present in the training room to assist the participants during the training session. The evacuation tests were conducted by two operators located in two separate test rooms. Two researchers welcomed and guided the participants to the rooms where the intake interview, training and tests were conducted. They also performed the intake interview and took the health measurements. The test coordinator had real-time views of the two test rooms and communicated with the other research team member by means of a two-way radio.

5.6.3 Setup of experiments

Experiments in the real environment
The test sessions consisted of an evening session and a night session, although the participants were told only about the evening session. In the evening session, an intake interview, a group meeting and a fake test took place. At night, the participants were required to evacuate individually. This evacuation was the actual test.

The participants arrived at the hotel individually or in small groups between 4 PM and 6 PM. After each participant was settled in a hotel room, he or she was asked to come to an assembly room in the hotel that had been equipped for an intake interview and for taking some health tests. The answers to the health questions that had been given by the participant in the online questionnaire had been integrated into a health certificate. The researcher discussed the health certificate with the participant and, if the participant agreed with the health statements in the health certificate, he or she signed the document. The researcher then measured the participant’s blood pressure and resting heart rate. These individual health interviews and measurements took place until approximately 7 PM. At 7 PM, there was a social dinner with all the participants and the members of the 'evening session research team'. After dinner, the participants took part in a group meeting and conducted an ‘individual test’, which was actually a fake test. During the individual tests, the participants socialised in the hotel bar. A member of the research team was present to accompany the participants and to coordinate the individual tests. The evening activities were designed to lead the participants to believe that the 'individual tests' were the focus of the research. Therefore, every evening session ended in the hotel bar with a social drink and a short presentation of the results of the individual tests. Some participants consumed alcohol, as might ordinarily take place during a regular overnight stay in a hotel, though alcohol consumption was limited to approximately three alcoholic drinks, generally beer or wine, per person. After the last drinks, the participants were thanked for their participation and the members of the research team went to their hotel rooms. At the end of the social session in the hotel bar, none of the participants were perceptibly under the influence of alcohol.

In total, twelve test sessions were conducted. To provide a reason for the hotel overnight stay, the participants in the last six sessions were told they would take part in a short group experimental session with ADMS-BART the next morning at 10:00 AM (this group session would not actually take place; the night sessions that consisted of individual evacuations were the real tests). A description of the evacuation test is presented in Section 5.4.3. The tests were conducted between (approximately) 02:15 and 06:45 AM, while the test persons were sleeping in their hotel rooms. Each participant was awakened by a telephone call with an alarm message. After he/she had reached the reception desk or had opened the fire exit, a safety warden took care of the participant and guided him/her to the interview room.

Experiments in the virtual environment
The test session consisted of an intake interview, a training session and an evacuation test. The intake interview and training session were the same at each test session. The evacuation scenario varied with different participants.

The participants arrived at the NIFV facility individually or in small groups between 9 AM and 12 AM or between 6 PM and 9 PM. A researcher welcomed the participants and conducted an intake interview. In the intake interview, the researcher discussed the health certificate with the participant, and the participant's blood pressure and heart rate (at rest) were measured. If the participant agreed with the health certificate and the measurement results, he or she was required to sign the health certificate. Some participants had not registered for participation and therefore had not completed the online questionnaire. These participants first completed the pre-test questionnaire and the health certificate and then the intake interview was conducted. After the intake interview, the participant waited in a waiting room to be invited to a BART training session. A description of the BART training is presented in Section 5.4.2.

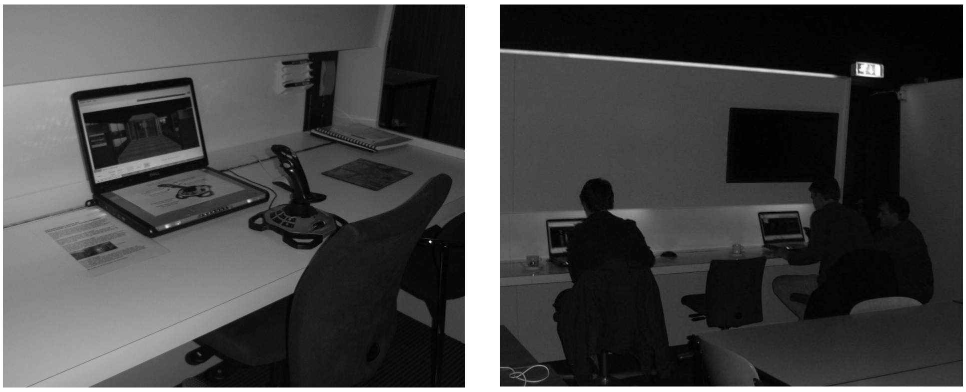


Figure 5.10. BART training session

A total of six participants could undergo the (individual) BART training session at the same time (see Figure 5.10). After the training session, each participant took part in an evacuation test (see Section 5.4.3) in one of the two test rooms. The individual evacuations were conducted in a darkened test room.

Figure 5.11. Test room setup
(in the experiment, the lights were off)

After the training session, the test person was guided to the test room by a research team member. Before entering the test room, the researcher explained the procedure of the experiment to the test person, who was then guided into the room. After he or she was in place, the researcher left the room and turned off the lights and the test began; at this point, the participant was to act as if it were a real situation. The situation was described by the researcher as a night situation in a hotel with the participant asleep in his/her hotel room. The projection took place on a 1.0 by 1.5-meter flat projection screen.

Figure 5.12. Viewpoint of participant
(during the experiments, the lights were off)

During the explanation of the experimental procedure, the operator, who was in the test room behind a screen (see Figure 5.12), prepared the settings of the test scenario in ADMS-BART. The preparation activities consisted of selecting the scenario, the hotel room in which the experiment was to take place and the fire settings. After the lights went out, the operator began the experiment. After the participant had reached the reception desk or had opened the fire exit, the operator told the participant that the test was over and informed the test coordinator. A research team member was sent to the test room and took the health measurements. After the measurements, the researcher guided the participant to the computer room to fill in the online questionnaire.

The research design for the validation of the serious game is presented in the next section.

5.7 Research design for validation of ADMS-BART

5.7.1 Introduction

The serious game ADMS-BART can also be labelled as a 'simulator'. Simulators have already been used for behavioural research, such as driving and flight simulators in particular. Simulators must have appropriate validity to be useful human factors research tools [Godley et al. 2002]. Blaauw (1982) proposed two levels of validity, namely the physical validity and the behavioural validity. *Physical validity*, often referred to as a simulator's fidelity, is the physical correspondence of a simulator's components, layout, and dynamics with its real world counterpart. *Behavioural validity*, commonly referred to as *predictive validity*, concerns the correspondence between the simulator and the real world in the way the human operator behaves. The two levels are not always related [Blaauw 1982], though it is often presumed that a simulator's fidelity incorporates behavioural validity [Godley et al. 2002]. This presumption possibly clarifies the fact that the number of published simulator behavioural validation studies is quite limited to date [Blaauw 1982; Harms 1996; Riemersma et al. 1990; Carsten et al. 1997; Törnros 1998; Hirata et al. 2007; Yan et al. 2008].

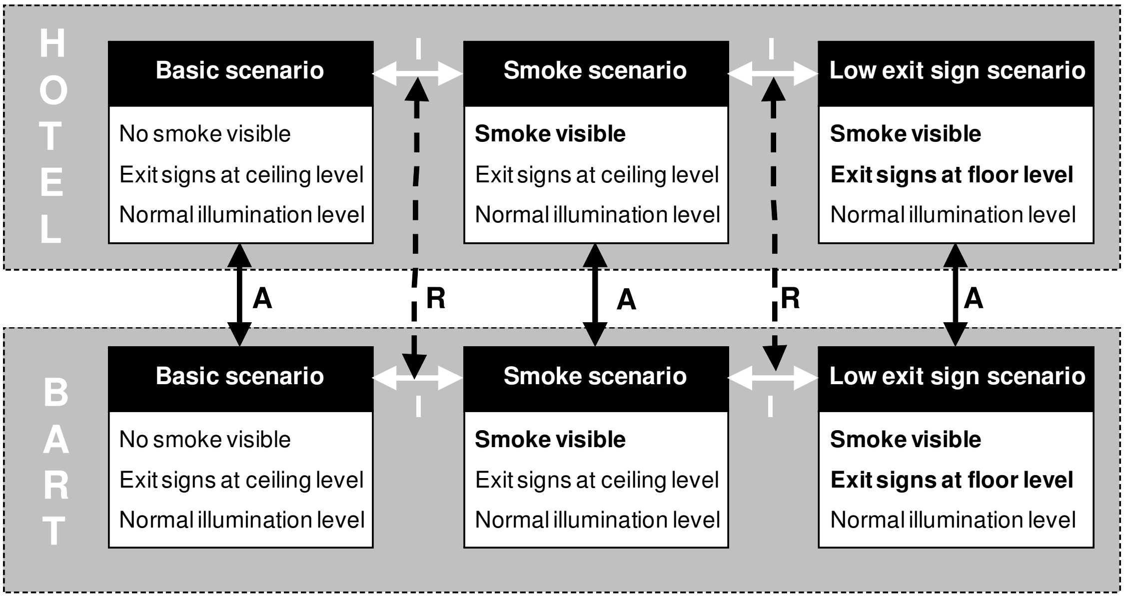
Blaauw (1982) argued that the most comprehensive method of undertaking behavioural validation research for the use of simulators is a comparison between the performance results in the simulator and the real world by using tasks that are as similar as possible in the two environments. The predictive validity can be described by two aspects: *absolute* and *relative validity* [Harms 1994; Blaauw 1982]. The former refers to the numerical correspondence between behavioural data in the simulator and the real environment, whereas relative validity refers to the correspondence between effects of different variations of the experimental conditions. Törnros (1998) observed that for a simulator to be useful as a research tool, it is necessary that the relative validity is satisfactory, i.e., the same, or at least similar, effects are obtained in both environments. Absolute validity is not a necessary requirement because research questions almost uniquely deal with matters relating to effects of various independent variables [Törnros 1998].

5.7.2 Validation procedure

To validate ADMS-BART evacuation, experiments were carried out in both a real hotel and a virtual hotel, which is a replica of the real hotel. The experiments for the validation of ADMS-BART were partially unannounced fire drills in which the participants were alarmed individually by means of a telephone message. A hotel building was selected as the object for closer research on human behaviour in fires. No participants tested in the real hotel experiment were also involved in the ADMS-BART experiment. However, it is common for validation studies to use the same participants in both experiments (Harms 1996; Törnros, 1998) although it is not always possible (e.g., Riemersma et al. 1990). The same participants were not chosen to participate in both environments because exposure to the evacuation wayfinding task in one environment might have influenced the participants' reactions in the subsequent experiment. Potential systematic bias and order effects were regarded as less desirable than generating additional between-participant variation by using a separate group of participants.

The tests that were part of the validation analysis were conducted under three situations, or scenarios. In the first scenario (basic scenario), nothing was changed in the hotel setting. In the second scenario (smoke scenario), a fire was simulated by pouring smoke out of a hotel room into the corridor. The smoke in the corridors blocked the route towards the main entrance. In the third scenario (low exit sign scenario), a fire was simulated, and the green exit signs were placed at floor level instead of at ceiling level.

The three scenarios were tested in both the real and virtual hotels. To validate ADMS-BART, the results of the basic, smoke and low exit sign scenarios in the real hotel were compared to the corresponding results from the virtual hotel (see 'R' and 'A' in figure 5.13). In the validation study, it was analysed to what extent the results concurred. The results consisted of a combination of certain vital actions, a certain exit choice (main exit, nearest fire exit, or other fire exit), and a certain route choice (total length of the chosen route) per scenario. Other studied results were the movement time and the motivations for the participants' behaviours.



I = Influence analysis, R=Relative validity analysis, A=Absolute validity analysis

Figure 5.13. Validation scenarios

The validation study consisted of four validation steps:
- Step 1: Analysis of possible differences in test group compositions,
- Step 2: Analysis of absolute validity (see 'A' in figure 5.13),
- Step 3: Analysis of relative validity (see 'R' in figure 5.13), and
- Step 4: Analysis of possible influence of the level of gaming skills on test results.

To justify using ADMS-BART for future experiments, the relative validation (step 3) was considered to be more important than the absolute validation (step 2). The processes of relative and absolute validation were conducted separately for each of the three scenarios (basic scenario, smoke scenario and low exit sign scenario). The procedures for the separate validation steps are presented in the following paragraphs.

5.7.3 Analysis of differences in test group compositions

The comparison of the experimental results can only be considered valid if there is an acceptable level of similarity between the groups of participants. Therefore, several variable characteristics of the group compositions were analysed, such as gender proportions and average age. The characteristics of the group of participants in the experiments in the real environment were compared to those of the participants in the experiments in the virtual environment. The comparison was conducted under the three situations: the basic scenario, the smoke scenario and the low exit sign scenario. The correspondence of the following variables was assessed:

- Profile of participants
    - Age (group average and standard deviation)
    - Gender (male or female)
    - Education (level 1: intermediate vocational or lower; level 2: higher vocational or academic)
- Prior knowledge of participants
    - Number of hotel stays per year (group average and standard deviation)
    - BET training (yes or no)
    - First aid training (yes or no)
    - Prior experience of being in a fire (yes or no)
- Starting location (room number)

5.7.4 Validation procedures for behavioural validity analysis

To assess the relative and absolute validity of the use of the serious game ADMS-BART, the procedures from the study of Törnros (1998) and Godley et al. (2002) were used.

The ANOVA analyses for the relative validity included estimating the effect size using the partial eta squared (η^2) statistic. This statistic was used because non-significant results validate the simulator, but non-significant results may arise from inadequate statistical power rather than a genuine absence of difference. If a large η^2 ($\geq$ 0.14) coincides with a non-significant result, it suggests that a difference perhaps exists but that it could not reach statistical significance due to an insufficient sample size and, thus, that it has an inadequate statistical power. If η^2 is small ($\leq$ 0.01), non-significant results can be more confidently proclaimed to reflect genuine non-differences. At or below $\eta^2 = 0.01$ (small effect), it can be presumed that even if there was a difference between the groups, it would be too small to be meaningful. Therefore, when a non-significant ANOVA analysis yields a $\eta^2 \leq$ 0.01, it can be claimed that the non-significant result arose from a genuine absence of difference rather than from insufficient power.

Absolute validation procedure

For absolute validation, the data collected in the two test environments were compared between each scenario. The nonparametric binominal test was used for testing the possible differences in exit choice (main exit, nearest fire exit or other exit).

The two independent-samples t-test was used for testing the possible differences in the following variables:

- distance walked to chosen exit (in meters),
- route deviation from shortest route to chosen exit (in meters), and
- movement time to chosen exit (in seconds).

Relative validation procedure
For the relative validation, the effects of the independent variables on the exit choice were analysed through ANOVA:

- environment (VE or RE) and
- scenario (basic, smoke or low exit sign scenario).

Godley et al. (2002) made a distinction between a treatment situation and a control situation. In the study with ADMS-BART, there were two pairs of treatment and control situations (see table 5.8).

Table 5.8. Pairs of treatment and control situations

Pair	Control situation	Treatment situation	Impact factor
Pair 1	Basic scenario	Smoke scenario	Environmental condition (smoke or no smoke)
Pair 2	Smoke scenario	Low exit sign scenario	Location of exit signs (low-placed or high-placed)

For each treatment and control situation, the participants' results in terms of the outcome variables were averaged. A disparity between a treatment and control mean value of the outcome variable represents the impact of the scenario treatment (smoke in corridor, low-placed exit signs). Relative validity is deemed to be fulfilled when these disparities are similar in magnitude and in the same direction in both environments (RE and VE). To analyse this issue statistically, a two-factor analysis of variance (ANOVA) was conducted with two situations (treatment and control) as a repeated measures factor and with the two test environments (RE and VE) as a between-participants factor. Relative validation was evaluated by examining the two-way interaction between the main effects of the scenario and the environment.

5.7.5 Analysis of possible influence of the level of gaming skills on test results

The fourth validation step, namely the analysis of a possible influence of gaming skills, was carried out to explore whether the results from the virtual hotel scenario were possibly influenced by the participants' level of gaming skills after training. The two-factor ANOVA test was used for testing the possible differences in gaming skills (after training) and the following variables:

- exit choice (main or nearest fire exit)
- route deviation by extra walking distance (centimetres)
- route deviation by exposed turning behaviour (yes or no)
- age (17-80 years)
- sense of stress (1-10 scale)
- clear organisation of lay-out (1-10 scale)
- ease of wayfinding (1-10 scale).

5.8 Methods of data gathering

5.8.1 Participant tracking form

During the initial interview, each participant received a participant tracking form in which the participant number and the test results of health measurements were recorded. The health measurements consisted of blood pressure and heart rate data of the participants. The first measurement was carried out during the initial interview. The form was used again after the evacuation test to fill in the results of the second set of health measurements.

In the tracking form that was used in the virtual environment experiments, the hotel room number was also recorded because it was needed for the training and test sessions. Furthermore, a cryptic sign for the test scenario was recorded because it was needed for the settings in the BART test. Two open-spaced boxes were on the form for the participants to record their self-assessed level of gaming skills before and after the training session.

5.8.2 Video recording

In the real hotel, the behaviour of the hotel guest (from the hotel room to the chosen emergency exit) was registered by means of cameras. Each vital action, such as changing view direction, changing movement direction, changing movement speed and opening doors, was registered along with the corresponding time. A set of four cameras connected to highly sensitive microphones was placed in the corridor near the hotel rooms in the experiment setting. During the tests, a technical assistant viewed and recorded the live movies.

Figure 5.14. Snapshot of video recording

The time (hh:mm:ss) as well as the test number (8052308** in figure 5.14) and the camera number (********01 in figure 5.14) were registered in the video recordings. Directly after the test, the technical assistant stopped the recording and edited the movie. This movie was used for the interviews with the participants conducted after the tests.

Figure 5.15. Control desk

In the virtual environment experiments, both the actions of the participants as well as the corresponding time and position were recorded automatically in ADMS-BART, and they were automatically stored in a database. Furthermore, the route choice was visualised on both a map and in a movie in ADMS-BART. Additionally, a set of four cameras connected to highly sensitive microphones was used both to obtain a live view of the experiment location and to register it. Two cameras were placed in the two test rooms in the experiment setting, and the other two cameras were placed in the training room.

5.8.3 Time measurements

In the real environment experiments, the evacuation times were measured by the research coordinator by using a stopwatch. The measurement of the alarm time started at the moment that the operator dialled the number of the hotel room and ended at the moment the participant put down the phone. The measurement of the reaction time started at the end of the alarm time and ended at the moment that the hotel room door was opened. After that, the measurement of the movement time commenced. The measurement of the movement time ended when the safety warden communicated via a two-way radio that the participant had either arrived at the reception desk or had opened the fire exit. In the virtual environment experiments, the evacuation times were measured and stored automatically by the ADMS-BART software.

5.8.4 Questionnaires

Two questionnaires were used in both experiment environments (real and virtual hotel), namely, a pre-test questionnaire and a post-test questionnaire. The questions were related to the critical factors of the human features in the FRP model, see Chapter 3. In table 5.9, an overview of the measured human features is presented. The items that were implemented in the questionnaires are marked by the symbol '#'.

The pre-test questionnaire was filled in after a person applied to participate in the experiment. It was an online questionnaire that consisted of:

- questions regarding health issues,
- questions regarding personal features, such as gender, age, education, prior knowledge of fire safety, etc., and
- two personality questionnaires, namely the Behavioural Inhibition System and Behavioural Approach System (BIS/BAS) and the Attention Control Scale (ACS).

After the evacuation test, the participants filled in a post-test questionnaire that included:

- questions about the perception of the evacuation situation,
- questions about the intentions and motivations for their evacuation behaviour, and
- a third personality questionnaire, namely the short Cognitive Emotion Regulation Questionnaire (CERQ short).

Table 5.9. Human features in a FRP model.

Item	Description	RE/VE	Variable or fixed
Profile	Age, gender, education level	RE+VE	Variable #
Personality	BIS/BAS, ACS, CERQ	RE+VE	Variable #
Knowledge and experience	Safety training, prior incident experience	RE+VE	Variable: present or not present #
	Hotel stay experience	RE+VE	Variable: number of stays per year #
	Prior inspection of escape route	RE+VE	Variable: yes or no #
Powers of observation	Participant selection	RE+VE	Fixed: good
Powers of judgement	Participant selection	RE+VE	Fixed: good
	Perception: opinions on situation	RE+VE	Variable: opinion level #
	Considerations	RE+VE	Variable: present or not present #
Powers of movement	Participant selection	RE+VE	Fixed: good
Affiliation	Some are friend or relative of another participant*	RE	Fixed: individual
	No friends or relatives in test setting	VE	
Task fixation	Route deviation by turning		Variable: yes or no
	Movement speed, evacuation time		Variable: m/s and seconds
Role	Hotel guest	RE+VE	Fixed: guest
Awareness	Asleep	RE	Fixed: low
	Awake	VE	Fixed: high
	Notices signage, escape route maps	RE+VE	Variable: yes or no #
Physical position	Lying in bed	RE	Fixed: passive
	Standing in front of screen	VE	
Familiarity with lay-out	First visit to hotel Veluwemeer	RE+VE	Fixed: not familiar

* Participants who showed affiliative behaviour were excluded from the analysis

Questions on health issues (health certificate)

Only healthy persons were allowed to participate in the evacuation tests. A health form was developed to verify the health level of the possible participants and exclude persons with specific health problems that may affect the safety of the participant during the evacuation test. The questions on the health form were incorporated into the pre-test questionnaire. The answers to health issues were used both to select possible participants and to formulate a personal health certificate for the selected participants. The selection of participants was based on medical approval by a qualified nurse. People who suffered from specific health problems, such as heart problems, epilepsy, asthma and limited sight, were excluded. Also, people who suffered from carsickness were excluded, as the sessions with BARTtrial revealed that some people who suffered from carsickness were found to experience symptoms of cyber sickness (see Section 6.4.2).

At the test location, an initial interview was carried out, wherein the researcher discussed the health certificate with the participant. Also, the blood pressure and the heart rate (at rest) were measured. If the participant agreed on the health certificate and the measurement results, the participant had to sign the health certificate. Based on the information in the assigned health certificate, the person either was or was not invited to participate in the evacuation test.

Questions regarding personal features

In the FRP model (see chapter 3), several personal features are included that may influence the fire response performance of a person. Therefore, questions were asked on the participants' profiles, such as on age, gender and education level. Other personal features that were measured included a prior knowledge of fire safety procedures as well as experience with a real fire which were divided based on prior fire experience (yes/no), BET training (yes/no), first-aid training (yes/no), number of hotel stays per year and the inspection of the escape route before the evacuation test (yes/no).

Also, the personality traits of the participants were measured and divided based on the score regarding the tendency of obedience to orders, tendency of risk-taking in emergencies, tendency of risk avoidance in emergencies, immunity level to stress, BIS/BAS score, ACS score and CERQ score. In this study, Dutch translations of the BIS/BAS, ACS and CERQ-short personality questionnaires were used. An introduction to the personality questionnaires BIS/BAS, ACS and CERQ-short is presented in textbox 5.1.

BIS/BAS questionnaire
The Behavioural Inhibition System and Behavioural Approach System (BIS/BAS) is a twenty-item self-report questionnaire that measures the behavioural inhibition and the behavioural approaches of people. The BIS scale correlates most highly with measures of trait anxiety, negative affectivity, negative temperament, harm avoidance and reward dependence. The BAS scale correlates most highly with measures of extraversion, positive affectivity and positive temperament. The scales are validated using experimental situations in which punishment or a reward were anticipated. Individuals scoring high in BIS sensitivity were found to react with greater nervousness when punishment was anticipated, while those scoring high in BAS sensitivity reacted with greater happiness when a reward was anticipated. Participants rated each item on a four-item Likert scale (1= almost never to 4 = always). Evidence for the reliability and validity of the BIS/BAS may be found in Carver and White [1994].

ACS questionnaire
The Attention Control Scale (ACS) is a twenty-item self-report questionnaire that measures the ability to focus (e.g., "When concentrating, I can focus my attention so that I become unaware of what is going on in the room around me") and shift attention (e.g., "I can quickly switch from one task to another") when necessary. Participants rated each item on a four-item Likert scale (1= almost never to 4 = always). Evidence for the reliability and validity of the ACS may be found in Derryberry and Reed [2002].

CERQ-short questionnaire
The short Cognitive Emotion Regulation Questionnaire (CERQ-short) is an eighteen-item self-report questionnaire consisting of nine conceptually distinct subscales, each consisting of two items and each referring to what someone thinks after the experience of threatening or stressful events: self-blame, referring to thoughts of putting blame of what you have experienced on yourself; other-blame, referring to thoughts of putting the blame of what you have experienced on the environment or another person; rumination, referring to thinking about the feelings and thoughts associated with the negative event; catastrophising, referring to thoughts of explicitly emphasising the terror of what you have experienced; putting into perspective, referring to downgrading the importance of the event; positive refocusing, referring to thinking about positive experiences instead of thinking about the actual event; positive reappraisal, referring to thoughts of giving the event a positive meaning in terms of personal growth; acceptance, referring to thoughts of resigning yourself to what has happened and planning, referring to thinking about what steps to take and how to handle the negative event. Participants rated each item on a five-item Likert scale (1= almost never to 5 = almost always). Evidence for the reliability and validity of the CERQ-short may be found in Garnefski and Kraaij [2006].

Textbox 5.1.

The main motive for collecting information on personality traits is to verify the similarity of the groups of participants in the separate scenarios. The BIS/BAS, ACS and CERQ short personality questionnaires were selected because they are scientifically endorsed and the traits that are measured by these questionnaires may have an influence on the participants' behaviours in the testing situations. The BIS/BAS questionnaire measures the behavioural inhibition and the behavioural approach of a person, the ACS questionnaire measures the ability to focus and shift attention when necessary, and the CERQ questionnaire measures cognitive coping strategies someone uses after having experienced a threatening or stressful event or situation.

Questions on perceptions, intentions and motivations
Several questions were asked to gain insight both into the participants' perceptions of the situation and into the intentions and motivations of their behaviours during the experiments. For example, the participant was asked to repeat the alarm message and to reveal the thought that he/she had upon hearing the message. Each participant was also asked if he/she had seen signals of fire, the green exit signs or the escape route maps and if he/she had made use of them. With regard to perceptions, the participants were asked to score their sense of emergency, sense of haste, sense of time pressure and sense of stress during the evacuation test. It was also asked whether the participant felt that he/she had accomplished the evacuation task with a good result (sense of good result). Other questions were related to their opinions of the hotel building lay-out, such as the level of a clear lay-out organisation and the level of the ease of wayfinding. With regard to intentions and motivations, questions were asked regarding considerations for the route and exit choices; for example, it was asked whether they opted for the familiar route or the shortest route.

For the questions on perceptions, intentions and motivations, the participant had to give an answer of 'yes' or 'no' and a rating on a 10-point scale. In the 10-point scale used, there is no 0-point item, though it basically has the same effect as an 11-point scale. For example, it is first asked whether a specific aspect is present for which the participant can answer with 'yes' or 'no'. If the participant gives the answer 'yes', then the participant has to answer a follow-up question regarding the intensity of the aspect's presence by giving a rating between '1' and '10'. Alternatively, an answer of 'no' would correspond to '0' on the 11-point scale. The answers to the two questions regarding 'presence' and 'level of presence' together, namely, the answer 'no=0' or the rating between '1' and '10', basically represent an 11-point response scale.

The (combined) 11-point scale was used because the target group of participants was familiar with an 11-point response scale; there is a tradition of using 11-point (0-10) scales in Europe in educational settings. It has also been found that the measurement quality of the responses is higher using an 11-point rather than a 5-point scale, particularly in behavioural measurements in European countries [Batista-Foguet et al. 2009]. More details regarding the comparison of an 11-point response scale to a 5-point Likert scale are presented in textbox 5.2.

The use of an 11-point scale versus a Likert 5-point scale
Assessment of the psychometric properties of behavioural assessments has often overlooked how the response modality may affect the findings [Batista-Foguet et al. 2009]. Likert 5-point scales continue to be used as the principal response scale in survey research. A 5-point Likert scale (including the CERQ-short questionnaire) is used for a majority of traits or behavioural competencies [Batista-Foguet et al. 2009]. Unfamiliarity with a 5-point Likert scale and familiarity with an 11-point response scale in European countries may affect the reliability of questionnaire responses, as the tradition of using 11-point (0-10) scales in Europe appears in academic and educational settings from primary school onwards. A study comparing the results of questionnaires with a 5-point Likert scale and an 11-point response scale with Spanish students revealed that the use of items measured by an 11-point scale leads to composite scores with higher reliability and lower invalidity than the use of a 5-point scale. The measurement quality of the responses is higher when using an 11-point rather than a 5-point scale. The findings suggest that the 11-point scale should be used more for behavioural measurements in European countries [Batista-Foguet et al. 2009].

Textbox 5.2.

5.8.5 Interviews following experiments in the real environment

Directly following the evacuation experiments, evaluation interviews were conducted. During the interview, the participant was asked to reveal the intention of his/her behaviour and to clarify his/her considerations. Therefore, after the recording of his/her evacuation was shown, the hotel guest was asked to answer some standard questions, such as:

- What was the extent of danger you perceived?
- Why did you choose that escape route and take those actions?
- What information did you get out of the communication and the design of the escape route?
- How did you interpret that information?

- Was the route choice based upon the escape route signs?
- What prior information and experience, related to both route choice and evacuation, did you have and did you use during the experiment?

The results of the interviews were used to verify the answers in the post-test questionnaires. Furthermore, they were used to explore a possible difference between the perceived and remembered situation compared to the real situation. The results of the latter analysis are presented in Section 7.2.9.

5.8.6 Overview of observed variables

The variables analysed in these experiments were studied for their possible influence on human fire response performance. The variable values were collected on a ratio scale, a nominal scale and an ordinal scale (see textbox 5.3).

Types of variables in the experimental research
Ratio variables: age, distance, time, personalities (13 aspects), number of hotel stays per year.
Nominal variables: environment (2 values), scenario (4 values), gender (2 values), prior knowledge (2 values), deviation by turning (2 values), use of signage/maps (2 values), presence of considerations (2 values), room number (11 values), exit choice (3 values).
Ordinal variables: education (2 values), perception, opinions and considerations (10 values).

Textbox 5.3.

The behavioural analysis data are presented below.

Building features:

- location of exit signs (high-placed or low-placed)
- lighting illumination level (normal level or low level)

Fire features:

- perceptibility of smoke (perceptible smoke or no smoke)

Human features:

- profile
  age, gender (male or female), education level (intermediate or higher vocational level)

- personality
  BIS/BAS, ACS, CERQ, obedience/dutifulness (1-10 scale), risk-taking in emergencies (1-10 scale), risk avoidant in emergencies (1-10 scale), immunity to stress (1-10 scale)
- knowledge and experience
  BET training (yes or no), first aid training (yes or no), prior experience of being in a fire (yes or no), hotel stay experience (number of hotel stays per year),
- safety behaviour
  prior inspection of escape route (yes or no), use of exit signs (yes or no), use of escape route maps (yes or no)
- movement behaviour
  exit choice (main exit, nearest fire exit, other exit), walked distance to exit (metres), route deviation by turning (metres), movement speed (m/s)
- evacuation time
  reaction time (seconds), movement time (seconds)
- perception of situation (1-10 scale)
  sense of emergency, sense of haste, sense of good result, sense of time pressure, sense of stress, sense of clear organisation of lay-out, sense of ease of wayfinding
- considerations for route choice (yes or no)
  fastest route, shortest route, safest route, familiar route
- decisive factor for route choice
  green exit signs, familiar route, fastest route

5.9 Participants, invitation and compensation

5.9.1 Invitation and compensation

The participants were invited either by colleagues, by a flyer or by an invitation on the webpage of NIFV or on a classified advertising website. People who were interested in participating in the research were asked to fill in an online pre-test questionnaire. The tests with BARTtrial were conducted at the facility of NIFV and took a half day to complete. In the *BARTtrial* tests, the compensation to the participants consisted of a free hotel room in the NIFV training facility, a free dinner, three free drinks at the bar, reimbursement of travel expenses and a coupon for € 25. The tests in the real hotel were conducted at Hotel Veluwemeer (four stars) and took a half day to complete. The compensation to the participants in the real hotel consisted of a free dinner, three free drinks at the hotel bar, a free overnight stay in a hotel room and reimbursement of travel expenses. The tests with ADMS-BART were conducted at the facility of NIFV and took approximately an hour to complete. The compensation to the participants in the BART experiments consisted of a free ticket to either the zoo or to an amusement park.

5.9.2 Excluded participants

In total, 107 people applied for the tests in the real environment; however, 24 people were either excluded from the test or the results of their tests were excluded from the analysis. Two people were excluded because of health reasons. The tests of three other people were not used in the analysis because those people were in the same room when the fire alarm went off. A fourth person was also in that room; however, that person evacuated individually and the results were included in the analysis. Several minutes later the three people evacuated together, and the evacuation was not recorded onto video. Two people alarmed other guests by knocking on several doors, thus requiring the research team to intervene. Four people were excluded because they were already awakened by others before the fire alarm went off. Six people stayed couple-wise in three rooms. One person returned to the hotel room after investigating the situation in the corridor and did not use an exit, another person was a fireman and evacuated via a window, and another person did not sufficiently fill out the questionnaire. Four people wore a headset camera to make a movie of the wayfinding behaviour from the participants' perspectives. The results of the evacuation tests of these four participants were analysed in the pre-validation analysis, though they were excluded from the behavioural and validation analyses.

5.9.3 Key information regarding the participants

In both environments, at least 20 people took part in a separate experiment scenario. A test person participated in only one evacuation test. In total, 176 evacuation tests were carried out successfully: 83 tests in the real hotel and 93 tests in the virtual hotel.

The number of participants and other participant features are given in table 5.9 based on the scenarios in both the virtual test environment (VE) and the real test environment (RE). The analysis of the group compositions on the key participant information is presented in Section 8.2.2.

Table 5.9. Key participant information.

Variable	Basic scenario (without smoke)		Scenarios with perceptible smoke				
			Smoke		Low exit sign		Lighting
	VE	RE	VE	RE	VE	RE	VE
Number of participants	24	20	23	39	23	24	23
Gender							
Male	46%	20%	44%	23%	44%	25%	39%
Female	54%	80%	56%	77%	56%	75%	61%
Age							
Age, average	38.0	41.3	32.2	34.2	38.4	41.4	38.0
Age, minimum	19	22	18	17	17	21	19
Age, maximum	71	73	60	65	74	67	70
Education level							
Intermediate vocational or lower	50%	40%	44%	54%	83%	33%	56%
Higher vocational or academic	50%	60%	56%	46%	17%	67%	44%
Prior knowledge and experience							
No. of hotel stays per year, average	5.8	4.4	3.1	5.5	3.3	7.8	7.6
BET training (yes)	21%	45%	26%	23%	26%	46%	26%
BET training (no)	79%	55%	74%	77%	74%	54%	74%
First aid training (yes)	42%	30%	35%	23%	39%	54%	44%
First aid training (no)	58%	70%	65%	77%	61%	46%	56%
Prior fire experience (yes)	4%	5%	4%	3%	4%	0%	4%

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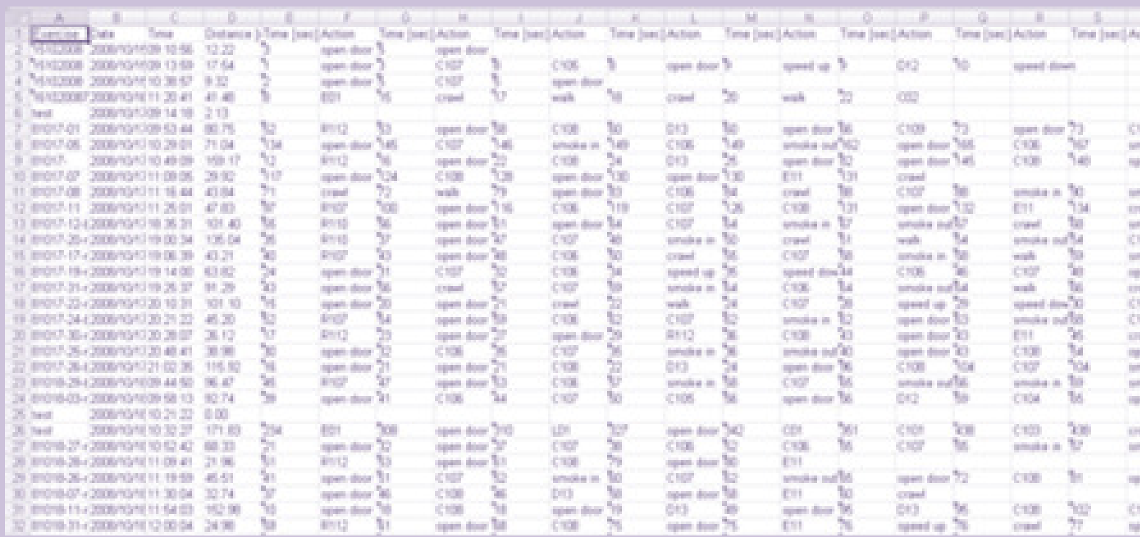

[Photos / snapshots by M. Kobes]

You have to have an idea of what you are going to do, but it should be a vague idea

Pablo Picasso (1881-1973)

Chapter 6

Development of the serious game ADMS-BART

In this chapter, the development of the serious game ADMS-BART is presented. The serious game is used as a research tool in experimental research (see chapters 7 and 8).The draft version of the research tool is BARTtrial. This draft version is used to test the user convenience of the research tool and to explore the possible necessities to of fine-tuning the serious game ADMS-BART during its development. User convenience has also been analysed in the final version of the tool, i.e., ADMS-BART.

The need for the new research tool is clarified in Section 6.1. A description of the simulation platform NIFV-ADMS and the design of the Behavioural Assessment and Research Tool (BART) are presented in Sections 6.2 and 6.3, respectively. Subsequently, in Section 6.4, the results of the user convenience analyses of the tests with BARTtrail are given, and in Section 6.5 a description is given of the implications of the user convenience test for the development of ADMS-BART. In Section 6.6, the results of analysis of the user convenience tests with ADMS-BART are presented. The conclusions and recommendations regarding the user convenience of the research tool are given in Section 6.7.

6.1 Need for a new research method

A new method of research is required to meet the need for insight into the decision-making processes used by evacuees. New methods that have been used in fire safety research include the use of simulations and serious gaming. In a simulation, the observations are predictions that are based on existing assumptions about a real situation. Therefore, it is not possible to collect new data on human behaviour. In a serious game, on the other hand, it is possible to expose people to the situation of a fire in a realistic way without exposure to the extreme health risk of a real fire. For that reason, the use of serious gaming seems to be a promising method for behavioural research in the future.

A serious game is defined as a game that uses interactive simulation by means of computer technology. An interactive simulation is a representation of the role of a human, the environment, or both, that will change during time if actions are or are not taken by the player.

To adopt the possibilities of virtual reality for studying human behaviour in fires, a new research method has been developed. This new method makes use of the serious game ADMS-BART, which is the Behavioural Assessment and Research Tool (BART), in the existing Advanced Disaster Management Simulator (ADMS) virtual training tool. This serious game has been specifically developed for conducting research on human behaviour in fires and fire safety psychonomics.

To test whether the serious game ADMS-BART is able to represent a realistic fire situation, and to make sensible use of the new research method possible, the game was validated by comparing the results of the experiments in the serious game with results of the same experiments in the real world. Moreover, it was tested whether the use of computer games in behavioural research is suitable for use by people with gaming experience as well as by people without gaming experience. In addition, a draft version of BART (BARTtrial) was used to analyse the user interface and the reality of visualisation. BARTtrial was also used in pre-validation tests (see Section 5.5.3).

6.2 The Advanced Disaster Management Simulator

6.2.1 Simulation platform

The Behavioural Assessment and Research Tool (BART) is based upon a well-tried and tested simulation platform that has been used by emergency training organisations all over the world for many years. This platform is the Advanced Disaster Management Simulator of ETC Simulation with the disaster scenarios of NIFV (NIFV-ADMS). NIFV-ADMS is a mobile, three-dimensional virtual reality team training system that can be used by all emergency disciplines. It lets participants deal with many different scenarios in all kinds of environments. Actions of the virtual resources are performed based on artificial intelligence and real time/tempo-based factors. It is an interactive, real-time, physics-based virtual environment with realistic 3D visuals and audio. It is possible to do research on the behaviour of both individuals and groups because the simulator uses multiple server-based networking processes to manage multi-user simulations.

The existing simulation platform is predominantly used as a training platform [Didderen et al. 2009]. Training simulations typically come in one of three categories:

- 'live' simulation, where real people use simulated (or 'dummy') equipment in the real world;
- 'virtual' simulation, where real people use simulated equipment in either a simulated world or a virtual environment; and
- 'constructive' simulation, where simulated people use simulated equipment in a simulated environment. Constructive simulation is often referred to as 'war gaming' since it bears some resemblance to table-top war games in which players command armies of soldiers and equipment that move around a board.

ADMS provides virtual simulation as well as constructive simulation.

6.2.2 Development of NIFV-ADMS

The initial development of NIFV-ADMS started in 2000 after an in-house study at NIFV revealed a gap between classroom training and practical training [Didderen et al. 2009]. As NIFV includes the Fire Service Academy, the Academy for Medical Assistance in Accidents and Disasters, the Academy for Crisis Management and the Academy for Leadership Safety Regions, it was important to bridge the training gap. An additional study revealed that the gap could be bridged with virtual reality. Therefore, in 2001, the existing ADMS product of the ETC Simulation tailored from the American emergency responder system to the Dutch (European) system. NIFV-ADMS has been operational since January 2002.

Figure 6.1. Active experimentation in a safe environment

The NIFV training organisation is highly experienced in the use of virtual reality; from January 2002 to January 2009, over 700 days of training were accomplished, a total of over 15,000 people performed one or more training sessions with NIFV-ADMS. Among the trainees are paramedics, police officers and fire crew commanders in their role of (chief) officer in charge. Other trainees are operational officers of railways, council department employees, water agency employees and military personnel, such as military police and fire and medical service employees. About 95% of the participants are positive about training in a virtual reality environment. For example, most of the trainees who have worked with NIFV-ADMS consider the training in a virtual environment to be as stressful as a real emergency response [Didderen et al. 2009].

Today, NIFV trains with the fourth generation software version; updating the software is a continuous process in terms of both quantity of visuals as well as new software techniques. Currently, NIFV-ADMS has over 30 different incident locations involving road traffic incidents, hazardous material incidents, domestic fires, industrial fires and incidents in tunnels, railways and aircrafts. Each incident location has a scenario generator so that within one incident location, one can make dozens of different scenarios. Over 50 emergency vehicles ranging from fire brigade, police and EMR, including their personnel, are available [Didderen et al. 2009].

6.2.3 Foundations of the design of NIFV-ADMS

The design of training programs should ensure both that the context is clear for the trainees and that they are compliant with the real-world practices they are simulating. Important contextual factors for emergency responders are unexpected events, unknown situations, time pressure, and life threatening situations [Didderen et al. 2009]. Time pressure and unexpected or unknown situations result in stress. The available time for response is often underestimated, which causes people to experience even more time pressure. Another factor is that people filter information inappropriately under severe stress. The result of too much stress is that the capacity to make judgments in a proper manner decreases. Better decisions are expected when people have optimal preparation. The development of NIFV-ADMS and its training program is therefore based on the cognitive concepts of Klein (1998) and of Rasmussen and Vicente (1989).

The cognitive model of Rasmussen and Vicente (1989)

Skill-based
The decision maker reacts directly and is almost unaware of the situation. Examples are simple motor skills, such as driving and putting on a breathing apparatus.

Rule-based
The decision maker’s response is based on well-trained automated rules. This type is very closely related to skill-based decision making. An example is driving upwind and using foam on fuel spills.

Knowledge-based
Decision making based on knowledge. When a situation is new, one must think about the situation, goals and alternatives. One example is incident command.

Textbox 6.1.

The cognitive model of Rasmussen and Vicente (1989) is based on research involving coping with human error, and it distinguishes three types of decision-making: skill-based, rule-based and knowledge-based. For more details on the cognitive model of Rasmussen and Vicente, see textbox 6.1.

Klein (1998) conducted research on decision making under time pressure by experienced professionals. Recognition drives decisions according to Klein (1998). This implies that a decision maker must have a wide range of experience - a ready-to-use mental library of situations and solutions - to be prepared for his/her task. For more details on the cognitive model of Klein, see textbox 6.2.

The cognitive model of Klein (1998)

The model is composed of three steps:

Situation recognition
The decision maker recognises the situation as either known or new. With a known situation comes a known solution and actions that are frequently used or trained. An unknown situation requires unknown actions. Recognition occurs on the basis of some indicators and causal developing steps that explain to the decision maker the existing situation as well as the expected development of the situation. Based on this, the decision maker sets his achievable goals and selects an appropriate action as follows:

Serial comparison of alternatives
Relying on his/her experience, the decision maker develops a set of alternative actions that can lead to the intended goals. The order of these alternatives is determined by the extent to which they were used successfully in previous, similar situations. To examine if an alternative is appropriate, the decision-maker uses:

Mental simulation
The set of actions are simulated mentally to see how they will work and affect the situation. The decision maker will do this only for the first alternatives on his list. When an action seems to work, he/she will select it, even when it is not an optimal solution.

Textbox 6.2.

Thorough after-action reviews are important to both improve mental simulation and provide a good understanding of time/tempo factors. In virtual reality, it is possible to confront the participants with an environment that matches as much as possible the practical situation where skills will be applied.

6.3 Design of the Behavioural Assessment and Research Tool (BART)

6.3.1 Blueprint for BART

A blueprint for the design of BART was made to ensure that the research tool could be used to fulfil the research objective (see chapter 1). Several advisory sessions were called to explore the possibilities and impossibilities of the simulation platform of ADMS for use in behavioural research. A second purpose of the advisory session was to determine the programme of requirements for the design of BART. Therefore, advice was obtained from members of the NIFV training organisation (who also have participated in the development of NIFV-ADMS), from experts in the Architectural Design Systems Group of Eindhoven University of Technology, and from experts of ETC simulation (who also developed the NIFV-ADMS software). ETC Simulation has realised the technical and software issues of BART based on the detailed programme of requirements.

6.3.2 Functionalities of ADMS-BART

To make the software of ADMS suitable for behavioural research, it was extended to include several functionalities. For example, a tracking and registration device was implemented that generates the required data for behavioural analysis. With this device, a test person's movements within the virtual building are automatically stored. The tracking and registration device consists of a 3D real-time movie, a time/event database and a run path diagram.

In ADMS-BART, some influencing factors on fire response performance (see chapter 2) were implemented and can be adjusted to the specific aim of any behavioural experiment. Some examples of building and fire feature options in ADMS-BART are presented in table 6.1.

Given that the building and fire features can be changed and controlled easily in virtual reality compared to the real world, a multitude of alterations are possible. For example, a fire and a smoke layer can be simulated. The lower side of the smoke layer is determined at an altitude of 1.2 metres. When a test person walks in smoke, he/she experiences limited sight. An expected action in this situation is to crawl instead of walk through the building. Therefore, the test person can modify the viewing altitude during the experiment. When the test person decides to crawl, the maximum walking speed will decrease automatically.

Table 6.1. Examples of alteration options

Feature	Option 1	Option 2	Option 3
Location of exit signs	No exit signs	At ceiling level	At floor level
Visual access from inside to outside	Windows in corridors and glass in the staircase doors	No windows in corridors	No windows in corridors and / or no glass in staircase doors
Visual access to exits	Exit in side walls of corridor, thus no visual access to exit	Exit at end of corridor, thus visual access to exit	
	Exit at end of narrow side hall	Exit at end of wide side hall	
Illumination level	Normal level in corridors, approximately 100 lux	Emergency lighting level in corridors, approximately 1 lux	
Location of fire	In a room near the main exit	In a room near fire exit	In a staircase
Smoke	No smoke	Static smoke layer	Dynamic smoke development
Smoke velocity	Thin smoke	Thick smoke	
Situation outside	Night time / dark	Day time / light	
BET-members	No BET	BET-member 1 with message 1 and/or BET-member 2-5 with message 1	BET-member 1 with message 2 and/or BET-member 2-5 with message 1 or 2

6.3.4 Replica of Hotel Veluwemeer

An important functionality that was implemented in the simulator is the capability of visualising additional objects (such as a hotel). To make the visuals of the virtual environment as real as possible, pictures were taken of the interior and exterior of Hotel Veluwemeer, located near the Dutch city of Amersfoort. In figure 6.2, two photos are presented to give an indication of the correspondence of the virtual environment with the real environment. The pictures were taken by a software engineer at Movares who also developed the visual framework for the virtual hotel and its direct surroundings. The virtual object was made with the software VR4MAX. As it was possible to move around in the virtual hotel in VR4MAX, the virtual environment was used for some pre-validation tests and for primary user convenience tests. The draft version of the research tool in the virtual environment of VR4MAX is called BARTtrial.

Photo of nearest fire exit in real hotel

Photo of nearest fire exit in ADMS-BART

Figure 6.2. Correspondence of virtual environment with real environment

6.4 Results of user convenience analyses of tests with BARTtrial

6.4.1 Introduction

The main motive for conducting the user convenience test with BARTtrial was to explore the possible necessities for fine-tuning the serious game ADMS-BART during its development. A secondary motive was to gain experience with the process of training people to use the serious game. The differences between BARTtrial and ADMS-BART are given in table 6.2.

Table 6.2. Differences between ADMS-BART and BARTtrial

Functionality	BARTtrial	ADMS-BART
Walking in hotel	X	X
Fire and smoke		X
People present		X*
Sounds		X
Health indicator		X*
Tracking device		X
Database		X
3D real-time movie		X

* Functionality is not used in validation experiments

The results of the user convenience tests are presented in the following paragraphs.

6.4.2 Design of tests

The user convenience tests consisted of a series of five exercises in BARTtrial and one time test. The first three exercises were conducted behind a laptop screen with three types of controlling devices: a joystick, a gamepad and a keyboard with mouse (see figure 6.3). After these exercises, the participant had to fill in a post-test questionnaire that included questions regarding the preference of the different controlling devices. Participants had to rate the user convenience of the three devices on a scale from 1 (low) to 10 (high).

Joystick Gamepad Keyboard and mouse

Figure 6.3. Three types of controlling devices

The following two exercises were conducted with two (additional) types of projections, namely a small screen of approximately 1.0 by 1.5 metres and a large screen of approximately 2.4 by 3.0 metres (see figure 6.4).

Laptop screen Small screen* Large screen*

Figure 6.4. Three types of projections
(* Lightning was turned off during test)

After completing these two exercises, the participant had to fill in a second post-test questionnaire that included questions regarding projection preferences by giving a rating on a scale from 1 (low) to 10 (high). Following the exercises, the participants performed a timed test, wherein they had to walk from the room to the outside as fast as possible. In the test, the participant was located in front of the small screen and used his/her preferred controlling device.

Cyber sickness

The term cyber sickness has been used to describe the motion sickness that is caused by virtual reality systems, and it has been associated with the occurrence of vection, which is an illusion of self-motion [Lo & So 2001; McCauley & Sharkey 1992; Hettinger & Riccio 1992]. Clear symptoms of cyber sickness are nausea, eye strain, headache, pallor and dizziness [LaViola 2000].

Textbox 6.3.

The tests were carried out during five evenings and nights (see Section 5.3.1). The first six people tested the large screen, laptop screen and the small screen. Two young women experienced serious symptoms of cyber sickness after standing for only a few seconds in front of the large screen and had to stop the test immediately. A third young woman reported experiencing a slight level of light-headedness. The other three people (males) reported no major difference in preference for the large screen compared to the small screen. Therefore, we eliminated the possibility of projection on the large screen for the other four test sessions.

6.4.3 Participants

In total, 27 people with ages ranging from 19 to 56 years (mean of 36.1 years) participated in the user convenience tests.

6.4.4 Results of projection screen preference

There was a significant difference between the preferences for the laptop screen and the small screen. In particular, the participants who had reported to have game control skills preferred the projection on the small screen (8.3) compared to the projection on the laptop screen. However, the user convenience of the projection on the laptop screen was also found to be adequate (mean value of 6.5). The results are shown in figure 6.5.

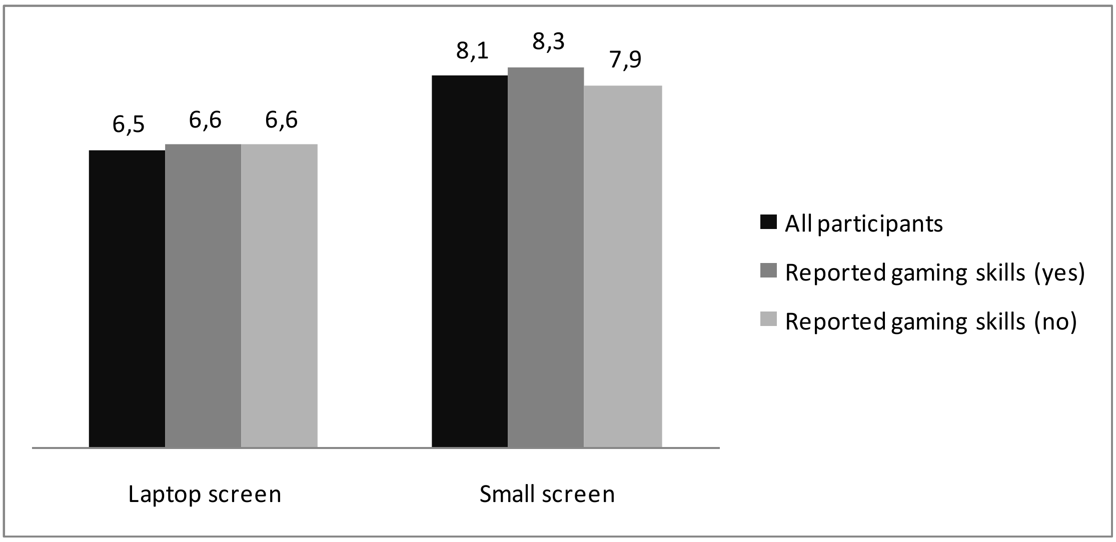

Figure 6.5. User convenience of projection types

6.4.5 Results of controller device preferences

In ADMS-BART, the type of controller had already been selected, namely, the joystick. However, for future development, we also tested the two other controller devices. The two most convenient controller devices are the gamepad and the joystick. There was no large difference between the preferences for the two devices; however, the participants with no self-reported game control skills gave the highest user convenience rating (7.5) to the joystick. The results are presented in figure 6.6.

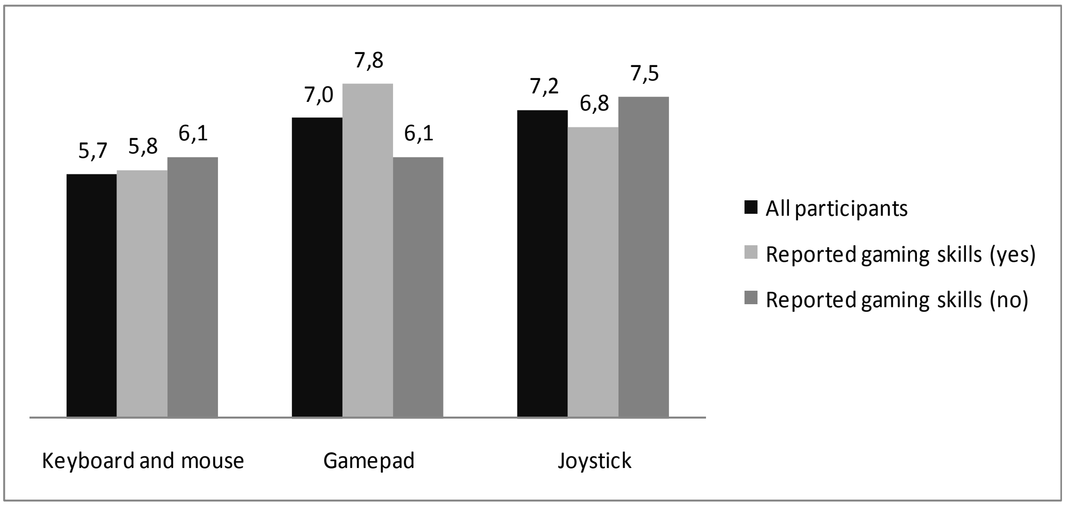

Figure 6.6. User convenience of controller device

The controller device preferences are presented in figure 6.7.

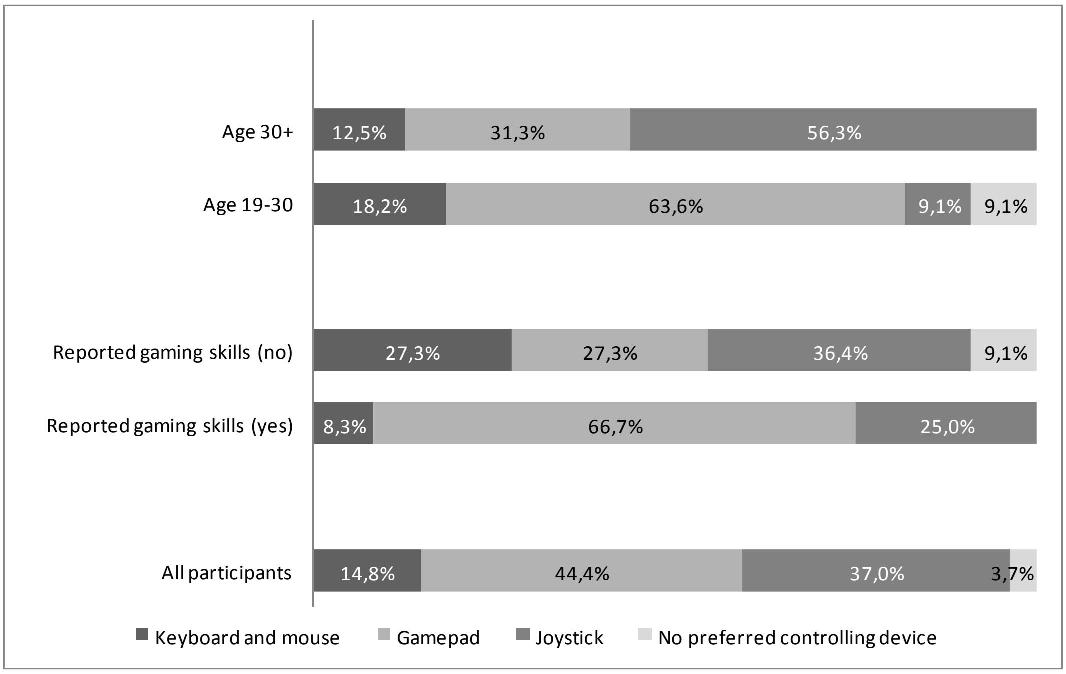

Figure 6.7. Preference of controller device

There is a difference in the controller device preference both between the younger (19-30 years) and older (30 years and older) participants as well as between the participants with no self-reported game control skills (mean age of 38.0) and those with self-reported game control skills (mean age of 33.1). The older participants and those with no game control skills found it difficult to learn to work with the keyboard and mouse in a short time. They preferred to use the joystick (56% and 36%, respectively). The younger participants and those with game control skills preferred to use the gamepad (64% and 67%, respectively).

6.4.6 Results regarding reality of visualisation

The visualisation in BARTtrial was valued as high, averaging 7.8 on a scale from 1 to 10. In particular, the participants with game control skills valued the reality of visualisation to be very high (8.4) (see Figure 6.8).

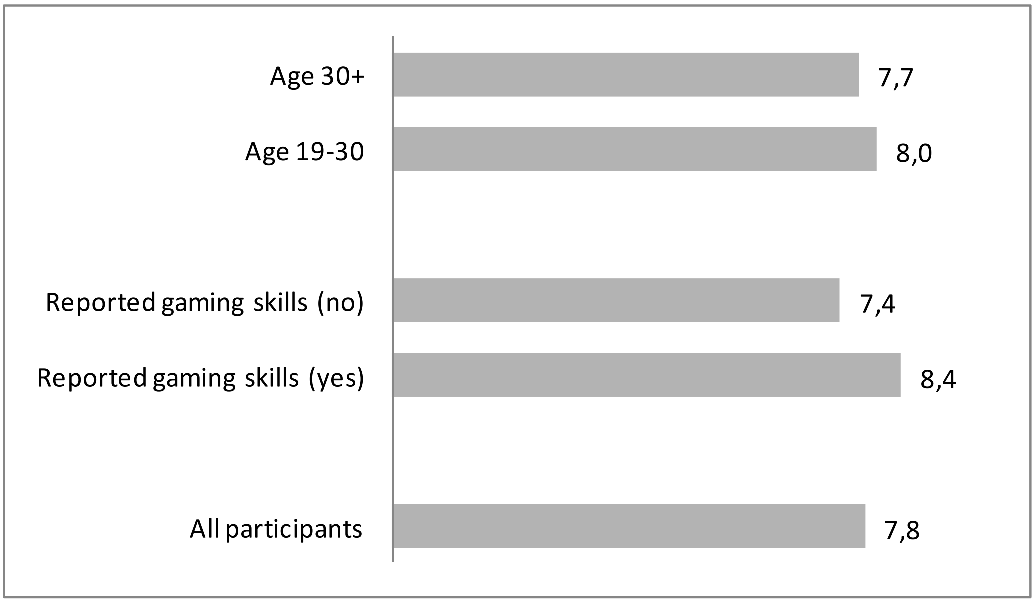

Figure 6.8. Reality of visualisation.

Most of the participants were very positive in their comments regarding the visualisation reality. Some participants declared: *"I have been walking in the (real) hotel before the exercise and I experience it (virtual hotel) as very realistic,"* and *"It can only be surpassed by using real video recordings."* Others declared: *"It looks good, though I miss other people such as hotel personnel."*

6.4.7 Conclusions of the convenience tests with BARTtrial

Three aspects of user convenience were tested with BARTtrial, namely, the preference of the project, the preference of controller device and the reality of visualisation. In total, 27 people with ages ranging from 19 to 56 years (mean of 36.1 years) participated in the user convenience tests.

The participants preferred the projection on the small screen (mean value of 8.1) compared to the projection on the laptop screen (mean value of 6.6). The two most convenient controller devices were the gamepad (mean value of 6.4) and the joystick (mean value of 7.9). The older participants (30 years and older) and those with no game control skills (mean age of 38.0) found it difficult to learn to work with the keyboard and mouse in a short time. The reality of visualisation in BARTtrial was valued as high (mean value of 7.4). In particular, the participants with game control skills valued the reality of visualisation to be very high (mean value of 8.1).

6.5 Implications of user convenience test for the development of ADMS-BART

6.5.1 Projection screen

The first tests with BARTtrial revealed that a large projection screen can cause cyber sickness. In an interview with the people who suffered from symptoms of cyber sickness, it was found that they also suffered from carsickness. Also, in the cyber sickness literature, a correspondence has been found between symptoms of motion sickness, which can be experienced during transportation, and cyber sickness [Lo & So 2001; McCauley & Sharkey 1992; Hettinger & Riccio 1992]. Therefore, people who suffered from carsickness were excluded from participation in the following sessions as well as in the sessions with ADMS-BART and the sessions in the real hotel. Furthermore, in the initial interviews in the sessions with ADMS-BART, significant attention was paid to identifying possible sensitivity for cyber sickness. As the user convenience of the projection on the small screen was relatively high (mean value of 8.1), the small screen was used in the test sessions with ADMS-BART.

6.5.2 Controller device

The existing tool NIFV-ADMS is controlled by a mouse and joystick. To explore whether a gamepad would result in a higher convenience, tests were conducted with a joystick, a keyboard and mouse and a gamepad as the controller device. The user convenience tests revealed that the gamepad was only preferred (mean value of 7.8) by participants with self-reported game control skills, although the use of the joystick was also assessed as being amply sufficient (mean value of 6.8). The participants with no self-reported game control skills gave the highest user convenience rating (mean value of 7.5) for the joystick. As the research tool ADMS-BART has to be suitable for participants with and without game control skills, the joystick was used as the controller device in the test sessions with ADMS-BART. Figure 6.9 shows how the movements in the virtual hotel were controlled.

6.5.3 Reality of visualisation

Since the reality of visualisation in BARTtrial was valued to be high (mean value of 7.4), no visual revision was needed for the test sessions with ADMS-BART.

Figure 6.9. Game control by using a joystick

6.6 Results of user convenience analyses of tests with ADMS-BART

6.6.1 Introduction

The ser convenience tests were also carried out with ADMS-BART. The motives for conducting the user convenience test with ADMS-BART included the ability to get a picture of the participants' perceptions of the simulated environment, to explore the user-friendliness of the serious game and to get a picture of the target group in terms of the level of gaming experience and age. The user convenience test with ADMS-BART was part of the evacuation test (as the user convenience test consisted of the training session and the evacuation exercise with ADMS-BART), after which a questionnaire had to be filled in.

6.6.2 Design of tests

The tests in ADMS-BART took approximately an hour and consisted of an initial interview, a training session and an evacuation test (see Section 5.6.3). Before the test, the participants registered and filled in an online pre-test questionnaire. The training session consisted of an exercise in ADMS-BART. Before the training, the participant had to give a grade for his or her level of game control skills on a scale from 1 (low) to 10 (high). The same question was asked after the training. Then, the participant took part in an individual evacuation test in one of the two test rooms. After the test, the participant had to fill in the online post-test questionnaire. In this questionnaire, some questions were asked regarding aspects of user interface (such as ease of game control), gaming experience, game control skills and the perception of the incident situation. Furthermore, several aspects of fire evacuation behaviour were observed and registered by the research team.

6.6.3 Participants

The results of 93 tests (involving 93 participants) were used in the user convenience analysis. A total of 52 (55.9%) of the participants had no prior gaming experience. The age of the participants varied between 17 and 74 years. Other details of the participants are given in Table 6.3.

Table 6.3. Participant details

		Scenarios with perceptible smoke		
	Basic scenario (without smoke)	**Smoke**	**Low exit sign**	**Reduced lighting**
Number of people	24	23	23	23
Gender				
Male	46%	44%	44%	39%
Female	54%	56%	56%	61%
Age				
Age, mean	38.0	32.2	38.4	38.0
Age, minimum	19	18	17	19
Age, maximum	71	60	74	70
No gaming experience	63%	65%	39%	57%

6.6.4 Results of perception

The participants were asked about their perceptions on the environment and the situation. Figure 6.10 presents the results of three aspects regarding perception, namely, the grades for the level of realism of the environment, the level wherein the walking in the virtual environment feels like walking in a real environment and the level of perceived feeling of emergency.

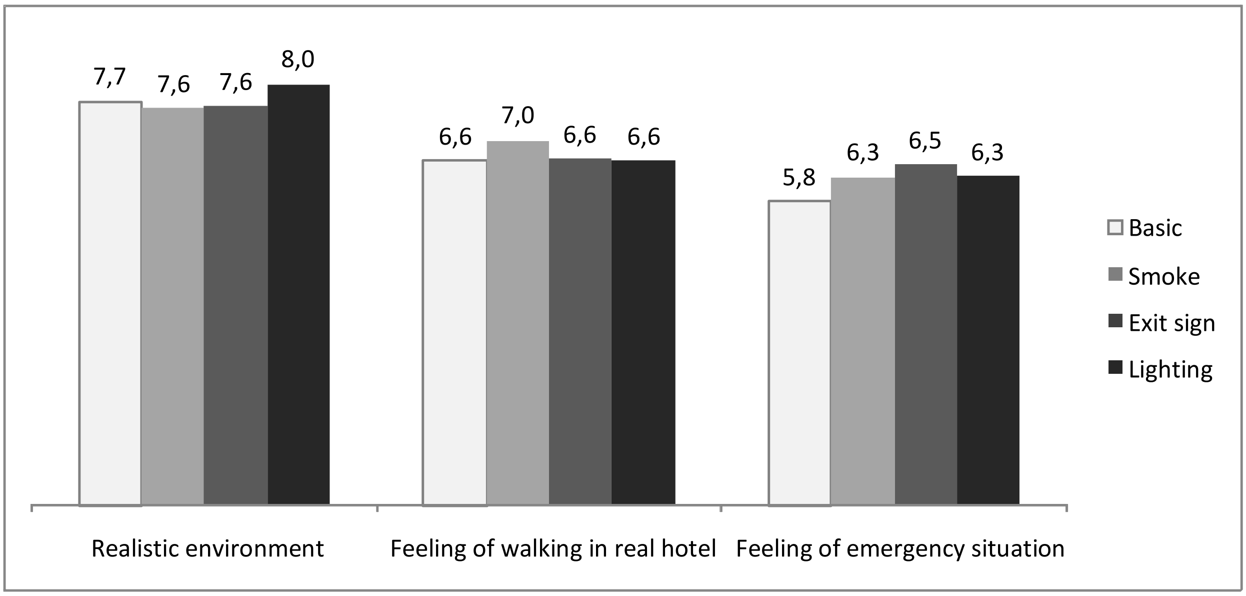

Figure 6.10. Perception of environment

Participants were asked to grade these aspects on a 10-point scale. The level of realism was found to be high (7.6-8.0), and the feeling of emergency was moderate (5.8-6.5). This indicates both that ADMS-BART can simulate a realistic environment and that participants in the tests in the serious game experience a feeling of emergency and evidently do not treat the situation as a “game”.

6.6.5 Ease of game control

In the post-test questionnaire, grades (scale 10-1) were requested regarding the ease of game control. The ease of controlling the game was judged to be high (7.0-7.7). Thus, ADMS-BART is easy to control. Participants experienced little difficulty in turning to the left or right (6.4-7.6); however, the grades were amply sufficient for conducting the wayfinding tests. More results of the ease of game control are given in figure 6.11.

As the ease of controlling the game was judged to be high, there are no reasons to assume that the man-machine-interface would affect the behaviour in the virtual environment.

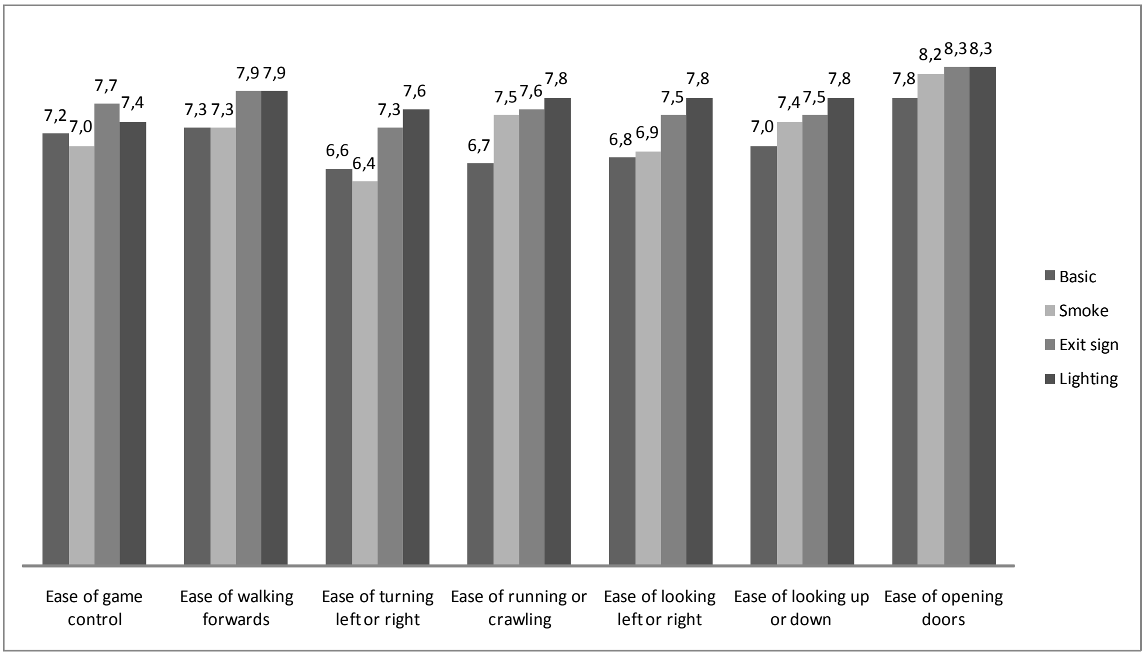

Figure 6.11. Ease of game control

6.6.6 Results of the influence of training on game control skills

As many participants had no game control skills, they were (individually) trained in controlling the game before the test. The duration of the training varied between about fifteen minutes to an hour. Before the training, the participants graded themselves with regard to their game control skills (N=88, 5 missing results). The average grades for game control skills before the training session were 5.6 (SD 2.6) in the basic scenario, 5.9 (SD 2.0) in the smoke scenario, 6.0 (SD 1.7) in the low exit sign scenario and 5.9 (SD 1.7) in the lighting scenario. After the training session, the participants graded themselves again. The average grades were 6.6 (SD 1.8) in the basic scenario, 6.8 (SD 1.3) in the smoke scenario, 7.0 (SD 1.1) in the low exit sign scenario and 6.7 (SD 2.0) in the lighting scenario. The results are presented in figure 6.12.

The average grades after the training session were approximately one point higher than before the training, although the influences of the training sessions may have varied per participant. To test whether the training had a significant (positive) influence on the level of game control skills, a paired samples test was conducted in SPSS. The 88 people in total scored an average grade of 5.9 points (SD 2.0) before the training and 6.8 points (SD 1.6) after the training. The difference in grades before and after the training was significant ($p<0.01$).

Figure 6.12. Game control skills

To explore whether the difference between the grades before and after training was relatively higher for participants without gaming experience, the participant group with self-reported gaming experience was separated from the group of participants without gaming experience. The average grade of the group of participants with gaming experience after training (N=40, 1 missing result) was 0.5 points higher than before the training (before the training, the average grade was 6.8 points (SD 1.5), and it was 7.3 (SD 1.1) after the training). In comparison, the average grade of the group of participants without gaming experience (N=48, 4 missing results) after training was 1.3 points higher than before the training (the average grade was 5.1 points (SD 2.1) before the training and 6.4 points (SD 1.8) after the training). The difference in grades before and after the training was significant both for the participants with gaming experience ($p<0.05$) as well as for the participants without gaming experience ($p<0.001$). This indicates that the short training had a positive influence on the game control skills for both groups of participants, especially for the participants without gaming experience.

The results are presented in figure 6.13.

Figure 6.13. Game control skills of participants with or without gaming experience

6.6.7 *Results of the relationship between age and game control skills*

To explore whether the level of game control skills (after training) is related to age, the mean scores for game control skills after training were compared to the age of participants. The participants were divided into two groups, namely a group with a low level of game control skills and a group with a normal to high level of game control skills.

A total of 15 participants had a low level of game control skills after training, namely, 5 points or lower. The age of these participants varied between 28 and 78 years, with an average age of 46.4 (SD 13.7). The average age of the 71 participants who gave themselves 6 points or higher for game control skills after training was 34.6 (SD 13.7), and it varied between 17 and 74. There was a significant difference in average age between the participants with a low level of game control skills and a normal to high level of game control skills, $t(84) = 3.035$, $p = 0.003$.

To explore whether the significant difference had an influence on the exit choice in the behavioural tests, further analysis was conducted. It was found that half of the group of participants with a low level of game control skills, compared to about 41% of the group of participants with a normal to high level of game control skills, evacuated via the nearest fire exit . The results of the t-test showed no significant difference in exit choice between the two groups, $t(84) = 0.577$, $p = 0.565$. Thus, there is no reason to assume that the level of game control skills after training had an important influence on the exit choice of either group. This implies that it is not necessary to exclude older participants or participants with a low level of game control skills from evacuation tests in a virtual environment.

6.6.8 Conclusions of the user convenience tests with ADMS-BART

Three aspects of user convenience have been tested with ADMS-BART, namely the ease of game control, the influence of training on game control skills and the perception of the virtual environment.

A slight majority of the 93 participants (56%) had no gaming experience. Nevertheless, the ease of controlling the game was judged to be high (7.0-7.7). This indicates that ADMS-BART is easy to control. The movements in ADMS-BART are controlled by a joystick. The values regarding ease of game control are comparable to the results of the user interface test with the joystick in the BARTtrial (7.9). As many participants had no game control skills, they were (individually) trained to acquire these skills. A significant difference in the increase of the game control skills after training between participants with (N=40) and without (N=46) gaming experience was found. This indicates that the short training period had a positive influence on the game control skills of participants, especially for the participants without gaming experience. The average levels of game control skills of participants with and without gaming experience after training were 7.3 and 6.4 points, respectively.

6.7 Summary and conclusions

6.7.1 Synopsis

The Behavioural Assessment and Research Tool (BART) is based on a well-tried and tested simulation platform that has been used by emergency-training organisations all over the world for years as the Advanced Disaster Management Simulator of ETC Simulation with the disaster scenarios of NIFV (NIFV-ADMS). The development of NIFV-ADMS and its training program is based on the cognitive concepts of Klein (1998) and of Rasmussen and Vicente (1989). To make the ADMS software suitable for behavioural research, it was extended with several functionalities such as a tracking and registration device and a virtual replica of the Hotel Veluwemeer. The draft version of this research tool is called BARTtrial. This draft version was tested in user-convenience trials to explore the possible necessity of fine-tuning the ADMS-BART serious game during its development and to gain experience with the process of training people to use the serious game.

6.7.2 Conclusions from user-convenience tests with BARTtrial

Conclusion 6.1: The user convenience of the projection on the small screen was relatively high (a mean value of 8.1).

> The rating for the projection on the laptop screen was also amply sufficient (a mean value of 6.6). Tests in a virtual environment with projection onto a large screen were found to cause cyber-sickness, i.e., with symptoms related to those of motion sickness. Therefore, the large screen was not used in subsequent test sessions with ADMS-BART.

Conclusion 6.2: The joystick game-control device scored the highest rating in the user-convenience tests.

> The participants with no self-reported game-control skills gave the highest user-convenience rating (a mean value of 7.5) for the joystick. The participants with self-reported game-control skills preferred the gamepad (a mean value of 7.8); the rating for the joystick was also satisfactory (a mean value of 6.8) for this group of participants.

As the research tool ADMS-BART must be suitable for participants both with and without game-control skills, the joystick was used as the controlling device in subsequent test sessions with ADMS-BART. The older participants (30 years and older) and those with no game-control skills (a mean age of 38.0) found it difficult to learn to work with the keyboard and mouse in a short time. Therefore, it is recommended to exclude the keyboard and mouse as controlling devices if a serious game is used to conduct behavioural research with a normal population.

Conclusion 6.3: The reality of visualisation of BARTtrial was very highly rated (a mean value of 7.4). In particular, the participants with game-control skills gave a high rating for the visualisation (a mean value of 8.1). Consequently, no visual revision was needed for the test sessions with ADMS-BART.

6.7.3 Conclusions from user-convenience tests with ADMS-BART

Three aspects of user convenience were tested with ADMS-BART, namely, the ease of game control, the influence of training on game-control skills and the perception of the virtual environment. In total, 93 persons participated in the user-convenience tests with ADMS-BART. As many participants had no gaming experience, they were (individually) trained in game-control skills. The average level of game-control skills of participants with gaming experience (n=40) was 7.3 after training; for participants without gaming experience (n=46) it was 6.4 points. There was found to be a significant difference in the level of game-control skills before and after training for participants both with and without gaming experience. This result indicates that the short training had a positive influence on the game-control skills of both groups of participants and especially for the participants without gaming experience. Therefore, it is recommended to train all participants in the use of the serious game if it is used to conduct behavioural research with a normal population.

Conclusion 6.4: ADMS-BART can simulate a realistic environment and participants do not treat the simulated situation as a 'game'.

The level of realism of the environment in ADMS-BART is found to be high, as it varies between 7.6 points in the 'exit sign' scenario and 8.0 points in the 'lighting' scenario. In addition, the feeling of emergency is moderate, as it varies between 5.8 points in the basic scenario and 6.5 points in the 'exit sign' scenario.

Conclusion 6.5: There are no reasons to assume that the man-machine-interface of ADMS-BART would affect behaviour in the virtual environment, as the ease of controlling the game is judged to be high (7.0-7.7), whereas half of the participants had no gaming experience.

There is a significant difference in average age between participants with a low level of game control skills and those with a normal-to-high level of game control skills ($p<0.01$). However, there is no significant difference in exit choice between participants with a low level of game control skills and those with a normal-to-high level of game control skills. Thus, there is no reason to assume that the level of game control skills after training had an important influence on the exit choice for either group of participants. This result implies that it is not necessary to exclude older participants or participants with a low level of game control skills from evacuation tests in a virtual environment.

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[Photos by NIFV: snapshots from video footage]

Speed is useful only if you are running in the right direction

Joel A Barker

Chapter 7

Wayfinding during Fire Evacuation in a Hotel: An Experimental Study

In this chapter, the results of the analysis on behavioural aspects of evacuation tests are presented. The experiments are partially unannounced fire drills in which the participants are alarmed individually by means of a telephone message. The experiments are carried out in a real hotel and in ADMS-BART. The analysis of the tests in the real environment is presented in Section 7.2. In the real environment, the basic scenario, the smoke scenario and the exit sign scenario are tested and analysed based on behavioural aspects. The results of the tests in the virtual environment are presented in Section 7.3. In the virtual environment, the basic scenario, the smoke scenario, the exit sign scenario and the reduced lighting scenario are tested, though only the results of the tests in the smoke scenario and the reduced lighting scenario are analysed based on behavioural aspects. Section 7.4 is a comparison between the results of the experimental research and the findings in the literature. The results of the analysis of the influence of human, building and fire features on the fire response performances of participants are given in Section 7.5. The chapter ends with conclusions and recommendations in Section 7.6.

Chapter 5 presented background information on the design of the experimental research. For example, the designs of the experiments conducted in the real hotel are presented in Section 5.6 and, in Section 5.10, additional data are given about the participants.

< This text is not publicly available >

[Situation in real hotel - Photo by M. Kobes]

[Situation in virtual hotel - Photo by M. Kobes]

Faith is taking the first step, even when you can't see the whole staircase

Dr Martin Luther King Jr (1929-1968)

Chapter 8

Validation of ADMS-BART

In this chapter, the results of the analysis on the validation of the use of the serious game ADMS-BART as a research tool are presented. In Section 5.7, more background information can be found on design of the validation research, and in Section 5.9, extra data about the participants are given.

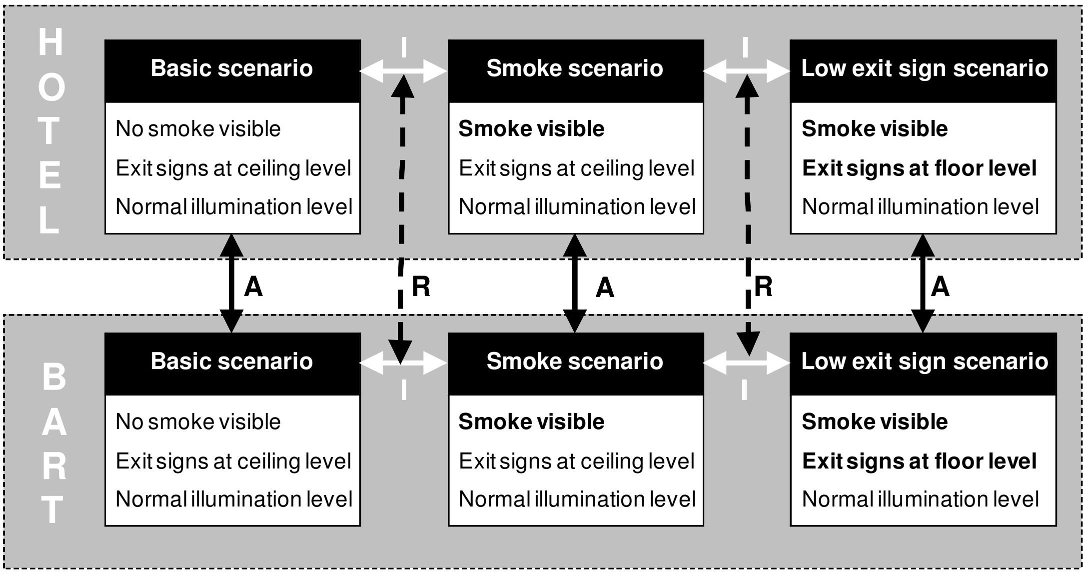
The validation study consisted of four validation steps. The first step consisted of analysis of the possible differences in test group compositions. The results of the analysis of step 1 are presented in Section 8.2. The second step was the analysis of absolute validity. The results of this analysis of the numerical correspondence between behavioural data in the virtual and the real environment are given in Section 8.3. The third step consisted of the relative validation analysis, wherein the correspondence between the effects of different variations in the experimental conditions was studied. These results are presented in Section 8.4. The fourth and last step involved the assessment of the potential influence of game control skills on the demonstrated behaviour. These results are given in Section 8.5. The chapter ends with conclusions, which can be found in Section 8.6.

8.1 Introduction

The application of a serious game in behavioural research is expected to be a valuable supplement to the existing research methods. For example, from research in adjacent areas, it appears that results that are achieved with a serious game are comparable with the data from experiments in real environments [Tan et al 2006; Godley et al 2002], see also Section 4.3.4. In the literature, no information exists concerning validation of the use of serious games for behavioural research in cases of fires, compared to conventional experimental studies. However, the use of a serious game, or simulator, as a research tool is only sensible if it has been validated by comparing the results of tests with the serious game with the same kinds of tests in a real world environment. Törnros (1998) observed that, for a simulator to be useful as a research tool, it is necessary that the relative validity is satisfactory, i.e., the same, or at least similar, effects are obtained in both environments. Absolute validity, i.e., numerical correspondence between behaviour data in the two test environments, is not a necessary requirement, because research questions almost uniquely deal with matters relating to the effects of various independent variables [Törnros 1998].

To validate ADMS-BART, evacuation experiments were carried out in a real hotel and in a virtual hotel, which is a replica of the real one. The experiments for the validation of ADMS-BART were partially unannounced fire drills in which the participants were alarmed individually by means of a telephone message. No participants of the real hotel experiment were also involved in the ADMS-BART experiment. The tests that were part of the validation analysis were conducted in three situations or scenarios, see Figure 8.1.

In the first scenario, nothing was changed in the hotel setting. This is called the basic scenario. In the second scenario, a fire was simulated by pouring smoke out of a hotel room and into the corridor. This is called the smoke scenario. The smoke in the corridors blocked the route to the main entrance. In the third scenario, a fire was simulated and the green exit signs were placed at the floor level instead of the ceiling level. This is called the low exit sign scenario.



I = Influence analysis, R=Relative validity analysis, A=Absolute validity analysis

Figure 8.1. Validation scenarios

The three scenarios were tested in both the real and virtual hotel. To validate ADMS-BART, the results of the basic, smoke and low exit sign scenarios in the real hotel were compared to the results of these scenarios in the virtual hotel. In the validation study, the extent to which the results concur in both relative and absolute validity analyses were determined (see 'R' and 'A' in Figure 8.1). To assess the relative and absolute validity, the procedures from the study of Törnros (1998) and Godley et al. (2002) are used. The results of the tests in the two environments consisted of a combination of certain vital actions, a certain exit choice (main exit, nearest fire exit or other fire exit) and a certain route choice (total length of the chosen route) per scenario. Other results that were studied were the movement time and the motivations for the participants' behaviours.

The validation study consisted of four validation steps:

- Step 1: Analysis of possible differences in test group compositions
- Step 2: Analysis of absolute validity (see 'A' in Figure 8.1)
- Step 3: Analysis of relative validity (see 'R' in Figure 8.1)
- Step 4: Analysis of a possible influence of the level of gaming skills on the test results

The results of the analyses for each of the four steps are presented in the following paragraphs.

8.2 STEP 1: Findings on group compositions

8.2.1 Introduction

The comparisons of the results of the experiments can only be considered valid if there is an acceptable level of comparability between the groups of participants. Therefore, several variable characteristics of the group compositions were analysed. The results of the comparison of group compositions between the real and virtual environment are presented in this section. Three aspects are evaluated, namely, the profile of the participants (Section 8.2.2), the level of prior knowledge of the participants (Section 8.2.3) and the start position of the tests (Section 8.2.4).

8.2.2 Profile of participants

In total, 153 tests of the three scenarios were successfully performed for the validation analysis. In every separate experimental scenario, both in the real hotel and in the virtual hotel, at least 20 persons took part.

Table 8.1. Key information for the participants

	Basic scenario (without smoke)		**Scenarios with smoke**				
			Smoke		**Low exit sign**		**Reduced lighting**
Variable	**VE**	**RE**	**VE**	**RE**	**VE**	**RE**	**VE**
No. of persons	24	20	23	39	23	24	23
Gender							
Male	46%	20%	44%	23%	44%	25%	39%
Female	54%	80%	56%	77%	56%	75%	61%
Age							
Age, average	38.0	41.3	32.2	34.2	38.4	41.4	38.0
Age, minimum	19	22	18	17	17	21	19
Age, maximum	71	73	60	65	74	67	70
Education level							
Intermediate vocational or lower	50%	40%	44%	54%	83%	33%	56%
Higher vocational or academic	50%	60%	56%	46%	17%	67%	44%

In Table 8.1, key information for the groups of participants is presented. To give a complete overview, the results of the 'smoke with reduced lighting scenario' are also presented in the table, though they were not used in the analysis for the validation of ADMS-BART. A one-way-ANOVA was conducted for all three scenarios as a whole. No significant differences were found between the groups in the real and virtual environments. The test shows that there is a significant difference for gender ($p<0.01$). In the tests that were used in the validation analysis, most of the participants were female. In the tests in the virtual environment, it was a slight majority, whereas in the real environment, more than two-thirds were female. Since all test groups contain 20 or more cases, it is appropriate to perform binominal tests for the analyses per scenario. The results of the binominal tests show that the gender difference was significant in the low exit sign scenario ($p=0.050$), as well as in the smoke scenario ($p<0.01$) and the basic scenario ($p<0.001$).

The one-way-ANOVA revealed no significant difference for age between the scenarios in the real and virtual environments. The average age of the participants was 32.2 in the smoke scenario and 41.4 years in the low exit sign scenario.

The distribution of the participants between the two educational levels of 'intermediate vocational level or lower' and 'higher vocational or academic level' are almost similar and roughly fifty-fifty, except for the participants in the low exit sign scenario. In the group that participated in the virtual environment, the majority (83%) had an intermediate vocational level or lower, and in the real environment the majority (67%) had a higher vocational or academic level. The results of the binominal tests show that the education level difference is significant ($p<0.001$) in the low exit sign scenario.

8.2.3 Personality traits

The participants filled out three scientifically endorsed personality questionnaires; specifically, the BIS/BAS, ACS and CERQ short questionnaires. The participants were also asked to give a self-assessment on a scale of 1 (low) to 10 (high) of their tendency to obey orders, take risks in emergencies, avoid risk in emergencies and their level of immunity to stress. In Table 8.2, the mean results are given.

Table 8.2. Personalities of participants

Personality	Basic scenario (without smoke)		Scenarios with smoke				
			Smoke		Low exit sign		Reduced lighting
	VE	RE	VE	RE	VE	RE	VE
	Mean	Mean	Mean	Mean	Mean	Mean	Mean
No. of persons	24	20	23	39	23	24	23
BIS total	18.8	19.0	18.8	18.1	19.5	17.9	19.5
BAS total	26.5	29.2	27.8	27.4	29.0	27.0	30.0
BAS reward	11.1	12.0	11.5	11.1	12.3	10.7	-
BAS drive	8.3	8.7	9.2	8.3	9.0	8.4	-
BAS fun	8.3	8.5	8.3	8.0	8.7	8.0	-
ACS attention	54.7	50.2	60.0	57.1	58.7	52.5	53.8
ACS focusing	24.6	22.6	22.9	23.1	21.8	22.4	21.8
ACS switching	31.6	27.6	35.5	34.0	35.8	30.1	32.0
CERQ total	46.8	47.1	46.1	45.9	46.1	52.0	46.6
Obedience / dutifulness	7.2	7.6	7.2	7.5	7.4	7.9	7.3
Risk taking in emergencies	5.8	6.8	5.9	5.5	5.7	6.0	5.6
Risk avoidant in emergencies	6.6	6.1	6.9	6.8	6.7	6.2	6.4
Immunity to stress	6.8	7.5	7.0	7.2	7.2	7.3	7.2

Table 8.3. Results of the T-tests between RE and VE

Variable	All scenarios		Basic scenario (without smoke)		Scenarios with smoke			
					Smoke		Low exit sign	
	t	p	t	p	t	p	t	p
BIS total	0.784	0.434	-1.369	0.178	1.161	0.250	1.492	0.143
BAS total	0.106	0.916	-2.358	**0.023**	0.415	0.680	1.684	0.101
ACS attention	2.151	**0.033**	1.502	0.141	1.068	0.290	2.176	**0.035**
ACS focusing	0.829	0.408	0.307	0.760	1.020	0.312	0.312	0.756
ACS switching	2.646	**0.009**	2.132	**0.039**	0.858	0.394	3.183	**0.003**
CERQ total	-1.168	0.245	-0.101	0.920	0.089	0.929	-2.441	**0.019**
Obedience / dutifulness	-1.464	0.145	-0.573	0.570	-0.729	0.469	-1.518	0.136
Risk taking in emergencies	-0.636	0.526	-1.536	0.132	0.736	0.465	-0.600	0.552
Risk avoidant in emergencies	1.005	0.317	0.892	0.378	0.098	0.922	1.045	0.302
Immunity to stress	-1.262	0.209	-1.084	0.248	-0.747	0.458	-0.263	0.794

The main motive for collecting information on personality traits was to verify the similarity of the groups of participants in the separate scenarios. In Table 8.3, it can been seen that there is no large difference in the measured personality traits between the test groups, except for the 'BAS total' ($p<0.05$) and the 'ACS switching' ($p<0.05$) scores in the basic scenario and for the 'ACS attention' ($p<0.05$), 'ACS switching' ($p<0.01$) and 'CERQ total' ($p<0.01$) scores in the low exit sign scenario.

The BIS/BAS scores were compared to the scores of an Australian community sample of 2,667 individuals aged 18-79 [Jorm et al 1998]. A total of 47% were males and 54% were females. In that sample, females scored higher on BIS and BAS reward scales, whereas males' scores were higher on BAS drive scales. There was no gender difference for the BAS total. Older groups scored lower on all of the BIS/BAS scales. The standard deviations of all of the BAS scales tend to increase in older age groups and these differences are statistically significant.

The BAS total score of the Australian community sample varied between 33.6 (aged 70-79) and 40 (aged 18-29). The mean score for the total group was 37.6. For the group of all males, it was 37.4, and for the group of all females it was 37.7. The BAS total score of the participants in the evacuation test varied between 27.0 and 30.0, which is relatively low. BAS scales correlate highest with measures of extroversion, positive affectivity and positive temperament [Carver and White 1994; Jorm et al 1998]. The relatively low BAS total score indicates that the group of participants in the evacuation test had a less positive and extroversive temperament than the individuals in the Australian community sample.

The BIS total score of the Australian community sample varied between 19.8 (aged 70-79) and 22.0 (aged 18-29) for females and between 18.8 (aged 70-79) and 19.3 (aged 18-29) for males. The mean score for the total group is 20.6. For the group of all males, it is 19.8 and for the group of all females it is 21.4. The BIS total score of the participants in the evacuation test varies between 17.9 and 19.5, which is relatively low though there is no large difference with the mean score of the Australian community sample. The BIS scale correlates most highly with measures of trait anxiety, negative affectivity, negative temperament, harm avoidance and reward dependence [Carver and White 1994; Jorm et al 1998]. The relatively low BIS total score indicates that the group of participants in the evacuation test have a more negative temperament and tend to avoid harm more than the individuals in the Australian community sample. This is underpinned by the relatively high scores on the trait 'risk avoidant in emergencies', namely, 6.1 to 6.9, compared to the trait 'risk taking in emergencies', namely, 5.5 to 6.0.

8.2.4 Prior knowledge of participants

The examined 'present' prior knowledge consisted of attendance at safety training, the average number of hotel stays per year and prior fire experiences. Another aspect of prior knowledge is the 'situational' prior knowledge, for example, the prior inspection of the escape route. The last aspect is analysed in Section 8.6.2.

Table 8.4. Prior knowledge

			Scenarios with smoke				
	Basic scenario (without smoke)		**Smoke**		**Low exit sign**		**Reduced lighting**
Variable	**VE**	**RE**	**VE**	**RE**	**VE**	**RE**	**VE**
Number of participants	24	20	23	39	23	24	23
Prior knowledge and experience							
No. of hotel stays per year, average	5.8	4.4	3.1	5.5	3.3	7.8	7.6
BET training (yes)	21%	45%	26%	23%	26%	46%	26%
BET training (no)	79%	55%	74%	77%	74%	54%	74%
First Aid training (yes)	42%	30%	35%	23%	39%	54%	44%
First Aid training (no)	58%	70%	65%	77%	61%	46%	56%
Prior fire experience (yes)	4%	5%	4%	3%	4%	0%	4%

The average number of hotel stays varies between 3.1 and 7.8 times per year, as presented in Table 8.4. The average number of hotel stays per year is relatively higher in the tests in the real environment, except for the tests in the basic scenario. The results of a one-way-ANOVA test show that the difference in the number of hotel stays between the real and virtual environment is not significant.

The BET training is training for Building Emergency Team (BET) members. In Dutch, it is 'BHV training'. This refers to training in first response to emergencies, such as giving first aid, extinguishing a small fire and starting and coordinating a building evacuation. A minority of participants had BET training, though in the basic scenario and the low exit sign scenario in the tests in the real environment it was just a slight minority. The difference in

BET training between the real and virtual environment is not significant in a one-way-ANOVA test.

The First Aid training refers to what in Dutch is called EHBO training. It differs from Dutch BHV training because an EHBO member needs to have a much more extensive knowledge of symptoms and injuries. The percentage of participants who had First Aid training varies between 23% and 54%. Obviously, the difference in First Aid training between the real and virtual environment is not significant.

Few participants have experienced a real fire in a building. The amount of 'prior fire experience' varies between none and 3% to 5% of the participants per scenario, which represents one person per scenario. The person in the basic scenario obtained the experience from participation in a youth fire service program for several years. The other people with prior fire experience revealed that they obtained the experience from a real fire evacuation.

8.2.5 Start position of the tests

The distribution of the participants on the 11 selected hotel rooms was determined by the researchers in order to make the start positions in both the real hotel and the virtual hotel comparable. In addition, the distribution was made comparable between the three scenarios.

8.2.6 Discussion and conclusions on group compositions

In comparable studies on building evacuation, normally details are only given on the gender and age of the participants. The difference in the fraction of males and females is significantly different ($p<0.01$) between the virtual and real environment, though the distribution of age is not found to be significantly different.

There is also no significant difference in the amount of prior knowledge or the start positions. In the additional, or unconventional, participant variables that were examined, there are dissimilarities in the personality traits and in the education level. In the basic scenario, there is a significant difference for two trait type scores, namely, for the 'BAS total' ($p<0.05$) and the 'ACS switching' ($p<0.05$) scores. In the low exit sign scenario, there is a significant difference for three trait type scores, namely, for the 'ACS attention' ($p<0.05$), the 'ACS switching' ($p<0.01$) and the 'CERQ total' ($p<0.01$) scores. In the low exit sign scenario, there is also a significant difference ($p<0.001$) in the education level of the participants.

8.3 STEP 2: Results of the absolute validation analysis

8.3.1 Introduction

Absolute validity refers to the numerical correspondence between behaviour data in the virtual and the real environments. In this section, the absolute validation analyses on exit choice (Section 8.3.2), distance walked (Section 8.3.3) and movement time (Section 8.3.4) are presented.

8.3.2 Exit choice

In the basic scenario, a slight majority of the participants evacuated via the main exit. In the smoke scenario and the low exit sign scenario, though only in the real environment, the majority evacuated by using the nearest exit. The results of the exit choice analysis are shown in Figure 8.2.

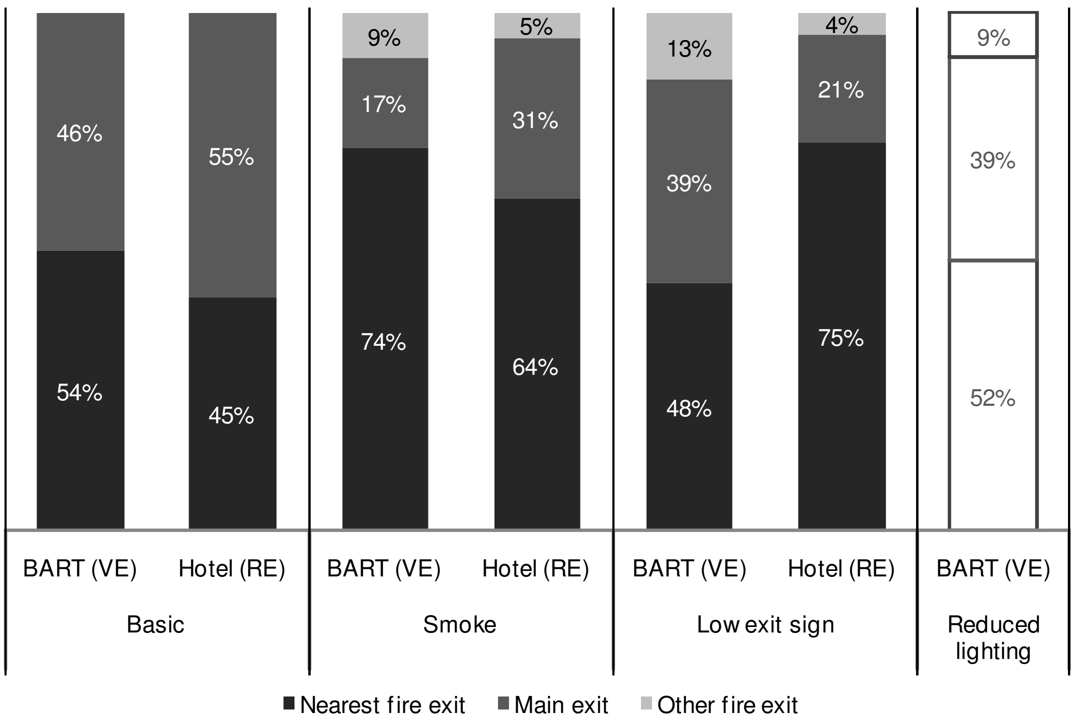


Figure 8.2. Exit choice

The results of the binominal test show no significant difference in exit choice between the real and virtual environment for the basic scenario or the smoke scenario, where a distinction is made between the choice for the nearest fire exit and another exit (the main exit or another fire exit). However, the difference in exit choice between the virtual and real environments is significant ($p<0.01$) in the low exit sign scenario.

Deviation from assumption
Figure 8.1 shows that in the low exit sign scenario in the virtual environment, the minority (48%) evacuated via the nearest fire exit, compared to 74% in the smoke scenario. This finding deviates from the assumption that when the exit signs are placed at floor level (low exit sign scenario) more participants tend to evacuate via the nearest fire exit than if the exit signs are placed at ceiling level (smoke scenario). Based on this assumption, it was expected that the fraction of participants that evacuated via the nearest fire exit would be larger than 74%, see bar 'Smoke, BART (VE)' in Figure 8.1. This assumption is found to be true for the tests in the real environment.

8.3.3 Distance walked and route deviation

The measurement of the distance walked in the real environment was based on the route choice and the measured distances between 'check points'. Thus, the distances walked in the real environment were 'calculated walked distances'. In the virtual environment, the distance walked was measured automatically, based on the movements in the virtual hotel. Thus, the distances measured in the virtual environment are more accurate than in the real environment. Nevertheless, to make a comparison between the walked distances in the two environments possible, the algorithm for calculating the walked distance in the real environment was also used for calculating the walked distance the virtual environment. The results are presented in Table 8.5.

The difference between the shortest egress route and the chosen route, if it is not the shortest egress route, is the route deviation. The results on route deviation are presented in Table 8.6.

The results of the T-test show that there is no significant difference in the (calculated) distances walked towards the main exit and fire exit between the real and virtual hotel. There is also no significant difference in the route deviation.

Table 8.5. Distance walked (m)

	Basic scenario (without smoke)			Scenarios with smoke					
				Smoke			Low exit sign		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Real hotel (calculated)	**20**	**54.3**	**31.0**	**39**	**35.9**	**22.5**	**24**	**32.7**	**30.6**
Fire exit (E11)	9	27.0	14.4	25	20.8	9.1	18	18.4	6.6
Main exit (E01)	11	76.6	21.1	12	65.6	6.2	5	61.3	2.8
Virtual hotel (calculated)	**24**	**47.0**	**22.3**	**23**	**45.1**	**36.6**	**23**	**55.5**	**34.5**
Fire exit (E11)	13	29.9	13.3	17	28.3	15.0	11	38.5	41.6
Main exit (E01)	11	67.3	9.7	4	68.3	8.4	9	66.7	9.1
Virtual hotel (measured)	**24**	**83.3**	**52.6**	**23**	**71.3**	**50.9**	**23**	**81.9**	**47.4**
Fire exit (E11)	13	45.3	25.2	17	43.5	1.7	11	48.1	38.4
Main exit (E01)	11	128.2	38.8	4	142.2	10.5	9	106.3	21.6

Table 8.6. Route deviation (m)

	Basic scenario (without smoke)			Scenarios with smoke					
				Smoke			Low exit sign		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Real hotel									
Route deviation (m)	**14**	**52.3**	**27.3**	**19**	**35.7**	**18.3**	**8**	**39.0**	**37.2**
Fire exit (E11)	3	19.1	16.0	5	13.4	11.0	2	6.5	2.1
Main exit (E01)	11	61.3	22.4	12	45.9	11.7	5	34.9	3.3
Virtual hotel									
Route deviation (m)	**16**	**38.9**	**15.7**	**12**	**48.2**	**39.8**	**17**	**47.0**	**35.3**
Fire exit (E11)	5	24.7	11.9	6	22.6	21.9	5	37.4 [a]	61.6 [a]
Main exit (E01)	11	45.4	12.8	4	50.9	15.0	9	46.2	14.2

a One person got lost and walked about 146 extra metres. By excluding this person the mean distance is 10.1 m with a standard deviation of 10.4 m.

Table 8.7. Turning behaviour and exit choice (%)

	Basic scenario (without smoke)		Scenarios with smoke				
			Smoke		Low exit sign		Reduced lighting
Variable	**VE**	**RE**	**VE**	**RE**	**VE**	**RE**	**VE**
Number of participants	24	20	23	39	23	24	23
Turning, yes	**7**	**5**	**10**	**8**	**6**	**4**	**8**
- via nearest fire exit	57%	20%	70%	62%	50%	75%	62%
- via other exit	43%	80%	30%	38%	50%	25%	38%
Turning, no	**18**	**15**	**13**	**31**	**17**	**20**	**15**
- via nearest fire exit	53%	53%	77%	64%	47%	75%	47%
- via other exit	47%	47%	24%	36%	53%	25%	53%

Some participants first headed towards the main exit and then turned and went towards the fire exit. The results for the fraction of participants who showed this turning behaviour are presented in Table 8.7. In the real environment, 25% of the participants in the basic scenario showed turning behaviour, 21% of the participants in the smoke scenario and 17% of the participants in the low exit sign scenario. In the virtual environment, the percentages were 29% in the basic scenario, 44% in the smoke scenario and 25% in the low exit sign scenario.

The results of the binominal tests show a significant difference in turning behaviour between the real and virtual environment for the smoke scenario ($p < 0.05$), but not for the other scenarios.

8.3.4 Movement time and movement speed

The movement time is the time between opening the hotel room door and the fire exit door or the arrival at the reception desk. The movement time and movement speed are presented in Table 8.8.

Table 8.8. Movement time and movement speed

	Basic scenario (without smoke)			**Scenarios with smoke**					
				Smoke			**Low exit sign**		
	N	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Real hotel									
Movement time (sec)	**20**	**58.0** [a]	**43.6** [a]	**39**	**41.8**	**30.6**	**24**	**43.0**	**41.4**
Fire exit (E11)	8	26.5 [a]	9.0 [a]	25	23.9	11.0	18	31.2	31.9
Main exit (E01)	11	80.9	44.7	12	77.3	29.0	5	58.8	15.5
Movement speed (m/s)	**20**	**1.0**	**0.5**	**39**	**0.9**	**0.4**	**24**	**0.9**	**0.4**
Fire exit (E11)	9	1.0	0.6	25	1.0	0.4	18	0.8	0.5
Main exit (E01)	11	1.1	0.4	12	1.0	0.3	5	1.1	0.3
Virtual hotel									
Movement time (sec)	**24**	**71.4**	**74.9**	**23**	**60.4**	**47.7**	**23**	**64.9**	**51.0**
Fire exit (E11)	13	36.5	21.8	17	36.6	23.8	11	32.8	27.6
Main exit (E01)	11	112.7	94.1	4	135.0	34.1	9	91.0	49.0
Movement speed (m/s) [b]	**24**	**1.4**	**0.5**	**23**	**1.3**	**0.4**	**23**	**1.5**	**0.4**
Fire exit (E11)	13	1.4	0.6	17	1.4	0.4	11	1.6	0.4
Main exit (E01)	11	1.4	0.5	4	1.1	0.3	9	1.4	0.5
Movement speed (m/s)	**24**	**0.9**	**0.4**	**23**	**0.9**	**0.3**	**23**	**1.1**	**0.4**
Fire exit (E11)	13	0.9	0.4	17	0.9	0.3	11	1.2	0.4
Main exit (E01)	11	0.8	0.4	4	0.5	0.2	9	0.9	0.4

a One person who evacuated via the nearest fire exit had a movement time of 254 seconds. With this test the mean movement time is 67.8 (SD 61.0), and for the participants who evacuated via the fire exit it is 51.8 (SD 76.3).

b Automatically measured movement speed in ADMS-BART.

The results are given for all of the tests for each scenario, for the group of participants that evacuated via the main exit and for the participants that evacuated via the fire exit.

The mean movement time towards the main exit in the virtual hotel averaged 1.6 times longer than in the real hotel, namely, 1.4 times longer in the basic scenario, 1.7 times longer in the smoke scenario and 1.5 times longer in the low exit sign scenario. The mean movement time towards the fire exit in the basic scenario was 1.4 times shorter in the virtual hotel than in the real hotel, though in the smoke scenario it was 1.5 times longer, and in the low exit sign scenario it is almost similar. The results of the T-test show that the differences are not significantly different between the basic scenario and the low exit sign scenario, although they are significantly different in the smoke scenario for the movement time towards the nearest fire exit ($p<0.05$), as well as for the movement time towards the main exit ($p<0.01$). As the movement time is measured manually in the real environment and automatically in the virtual environment, the measurements for the virtual environment are the most accurate.

Besides the movement time, the (approximate) distance walked was also determined. The movement speed is determined by dividing the distance walked by the movement time. The movement speed in the real environment is a 'calculated movement speed', because the measured walked distances are 'calculated walked distances'. As the movement time and the distance walked are measured automatically in the virtual hotel, the average movement speed is a ‘measured movement speed’. However, the participant has only four options for walking velocity in the virtual hotel, namely walking (fixed velocity of 1.0 m/s), running (fixed velocity of 1.2 m/s), crawling (fixed velocity of 0.8 m/s) and standing still (velocity of 0 m/s).

8.3.5 Discussion and conclusions about the absolute validation analysis

The absolute validation analysis reveals that there is no significant difference in exit choice between the real and virtual environment for the basic scenario and the smoke scenario. However, in the low exit sign scenario, a significant difference ($p<0.01$) is found in exit choice. In the virtual environment, it deviates from the assumption that if the exit signs are placed at floor level (low exit sign scenario) more participants tend to evacuate via the nearest fire exit than if the exit signs are placed at ceiling level (smoke scenario). This finding is counterintuitive; thus, further analysis is needed.

The absolute validation analysis reveals that there is no significant difference in the (calculated) walked distances towards the main exit and fire exit between the real and virtual hotel, or in their route deviations. This indicates that the use of ADMS-BART can be considered valid for research on walking distances.

There is no significant difference between the movement times in the basic scenario and the low exit sign scenario, though there are significant differences in the smoke scenario for the evacuation via the nearest fire exit ($p<0.05$), as well as via the main exit ($p<0.01$). These differences can be explained by the use of fixed movement speeds in ADMS-BART. Regarding the movement speed, it is important to take into account that the observations of the distances walked are not very accurate in the real environment and that the measured movement speed in the virtual hotel is based on four fixed walking velocities (running, walking, crawling, and standing). Thus, the results of the automatically measured movement speeds are not applicable for use in the evacuation calculation methods. Therefore, ADMS-BART is not assumed to be suitable for research on movement speeds during fire evacuation.

The use of ADMS-BART can be considered valid based on the absolute validation analysis for most of the aspects examined. There is, however, in the low exit sign scenario, a counterintuitive result concerning exit choice found in the absolute validation analysis. Nevertheless, absolute validity is not a necessary requirement for a simulator to be useful as a research tool. This is because research questions almost uniquely deal with matters relating to the effects of various independent variables [Törnros 1998]. Thus, it is necessary that the relative validity is satisfactory, i.e., the same, or at least similar, effects are obtained in the virtual and real environments [Törnros 1998]. The results of the relative validation analysis are presented in the following section.

8.4 STEP 3: Results of the relative validation analysis

8.4.1 Introduction

Relative validity refers to the correspondence between the effects under different variations in the experimental conditions. The similarities in the magnitude and direction of the effects are analysed in the real and virtual environment. To test the relative validity between the exit choice in the virtual and real test environments, two-factor analysis of variance (ANOVA) was conducted. For a description of the analytical method, see Section 5.7.4.

In this section, the possible impacts of different scenario treatments are presented. The disparity between the mean value for exit choice in the smoke scenario compared to the basic scenario, and in the smoke scenario compared to the low exit sign scenario, represent the impact of the scenario treatment (smoke in corridor, low placed exit signs). Two types of impact were analysed, namely:

- The impact of smoke in the corridor that blocks the route towards the main exit in the treatment situation and is not present in the control situation
- The impact of the location of the exit signs, which are placed low in the treatment situation and high in the control situation.

8.4.2 Impact of smoke on the exit choice

The assumption is that relatively more participants will evacuate via the nearest fire exit in the smoke scenario compared to the basic scenario. The route towards the main exit is blocked by smoke in this scenario, and it is therefore assumed that this will impede evacuation via the main exit. This assumption is found to be true in both environments (RE and VE), see Table 8.9. In the real environment, 64% of the participants in the smoke scenario evacuated via the nearest fire exit, compared to 45% in the basic scenario. In the virtual environment, 74% of the participants in the smoke scenario did evacuated via the nearest fire exit, compared to 54% in the basic scenario. Thus, in both environments (VE and RE) the participants in the smoke scenario evacuated more often via the nearest fire exit compared to the participants in the basic scenario. Moreover, the results of the two-factor analysis of variance (ANOVA) revealed a main effect for the scenario in both environments, $F(1, 102) = 3.937$, $p = 0.050$, $\eta^2 = 0.037$. Thus, there is evidence to conclude that the effect of the scenario (smoke or no smoke perceptible) in the virtual environment is comparable to the effect of the scenario in the real environment.

Table 8.9. Impact of smoke on exit choice

Variable	Real environment: Basic scenario	Real environment: Smoke scenario	Virtual environment: Basic scenario	Virtual environment: Smoke scenario
Number of participants	20	39	24	23
- Via nearest fire exit	45%	64%	54%	74%
- Not via nearest fire exit	55%	36%	46%	26%

Ideally there is a significant main effect for the scenario, and there is no interaction effect between the scenario and the environment. The ANOVA did not reveal an interaction between the effect of the scenario and the environment on exit choice, $F(1, 102) = 0.001$, $p = 0.335$. Since the effect size is very small ($\eta^2 = 0.009$), it indicates that the non-significant result arose from a genuine absence of difference, rather than insufficient power. This implies that there is no reason to assume that the effect of smoke is different between the virtual and real environments.

8.4.3 Impact of location of exit signs on the exit choice

The assumption is that relatively more participants will evacuate via the nearest fire exit in the low exit sign scenario compared to the smoke scenario. In the absolute validation analysis, it was already found that the exit choice in the virtual environment does not comply with this assumption. Specifically, in the smoke scenario, 74% of the participants evacuated via the nearest fire exit, compared to only 48% of the participants in the low exit sign scenario, see Table 8.10.

Table 8.10. Impact of location of exit signs on exit choice

Variable	Real environment: Low exit sign scenario	Real environment: Smoke scenario	Virtual environment: Low exit sign scenario	Virtual environment: Smoke scenario
Number of participants	24	39	23	23
- Via nearest fire exit	75%	64%	48%	74%
- Not via nearest fire exit	25%	36%	52%	26%

On the other hand, the assumption is found to be true in the real environment, as more participants (75%) evacuated by using the nearest fire exit in the low exit sign scenario compared to the smoke scenario (64%). In the virtual environment the participants in the smoke scenario evacuated more often via the nearest fire exit, whereas in the real environment the participants in the low exit sign scenario evacuated more often via the nearest fire exit. This difference is also found in the two-factor analysis of variance (ANOVA), as the results show that the main effect for the scenario is not significant, $F\ (1\text{-}105) = 0.664$, $p = 0.417$, $\eta^2 = 0.006$, nor for the environment, $F\ (1, 105) = 0.868$, $p = 0.354$, $\eta^2 = 0.008$. Moreover, the ANOVA revealed an interaction effect of scenario and environment on exit choice, $F(1, 105) = 3.937$, $p = 0.050$, with a small effect size ($\eta^2 = 0.036$). This means that the effect of the location of the exit signs is almost certainly different in the virtual and real environments.

8.4.3 Discussion and conclusions about the relative validation analysis

Two types of impact were analysed, namely, the impact of smoke on exit choice and the impact of the location of the exit signs on exit choice. It was found that there is no reason to assume that the effect of smoke is different in the virtual and real environments. On the other hand, the relative validation analysis of the effect of the location of the exit signs revealed that the effect is probably different in the virtual and real environment. This difference is probably due to an inconsistent finding in the absolute validation analysis, as the exit choice in the low exit sign scenario in the virtual environment does not comply with the assumption that in the low exit sign scenario relatively more participants will evacuate via the nearest fire exit than in the smoke scenario. Thus, further analysis of variables that could have potentially influenced exit choice was conducted. The results are presented in the following section.

8.5 Further analysis of potential explanatory variables

8.5.1 Introduction

In this chapter, the results are presented of further analysis of other factors (than only the test scenario) that possibly could have influenced exit choice. This analysis was conducted because, in the low exit sign scenario, a significant difference was found in the exit choice between the virtual and real environments. Additionally, the exit choice in the low exit sign scenario in the virtual environment deviates from the assumption that if the exit signs are placed at floor level (low exit sign scenario) more participants tend to evacuate via the nearest fire exit than if the exit signs are placed at ceiling level (smoke scenario).

To find an explanation for this, the possible influence of group compositions was analysed (Section 8.5.2), as well as the possible influence of exit choice motivations, namely, considerations (Section 8.5.3), fire safety attitude (Section 8.5.4), which includes the use of exit signs, prior inspection of the escape route and the use of escape route maps, and the possible influence of the perception of the situation (Section 8.5.5).

The rationale for the analysis of the possible influence of group compositions is the finding of a significant difference between VE and RE for gender, the educational level and several personality traits in 'Step 1' of the validation study (see Section 8.2). The rationale for the analysis of the possible influence of motivations and perceptions is the theory that an occupant's fire response performance is influenced by their prior knowledge and experience, their powers of judgement, their awareness (i.e., if they notice the presence of signage and escape route maps) and their perceptions of the information that is given by surrounding 'signals', such as smoke and exit signs. This theory is explained in the FPR model in Chapter 3. This model is incorporated in the questionnaires that are used in the experimental research, see Section 5.8.4.

8.5.2 Impact of group compositions on exit choice

It is found that the group compositions is significant different between the virtual and real environments for gender. In the low exit sign scenario, there is also a significant difference found for the education level and for the personality traits 'ACS attention', 'ACS switching' and 'CERQ total'. In the basic scenario, there is an additional difference between the virtual and real environment for the personality traits 'BAS total' and 'ACS switching'.

Table 8.11. Considerations and exit choice

	Basic scenario (without smoke)		**Scenarios with smoke: Smoke**		**Low exit sign**		**Reduced lighting**
	VE	**RE**	**VE**	**RE**	**VE**	**RE**	**VE**
No. of persons	24	20	23	39	23	24	23
Gender							
Male	**<u>46%</u>**	**<u>20%</u>**	**<u>44%</u>**	**<u>23%</u>**	**<u>44%</u>**	**<u>25%</u>**	**39%**
- via nearest fire exit	54%	25%	70%	67%	50%	83%	67%
- via other exit	46%	75%	30%	33%	50%	17%	33%
Female	**<u>54%</u>**	**<u>80%</u>**	**<u>56%</u>**	**<u>77%</u>**	**<u>56%</u>**	**<u>75%</u>**	**61%**
- via nearest fire exit	54%	50%	77%	63%	44%	72%	43%
- via other exit	46%	50%	23%	37%	56%	28%	57%
Education level							
Intermediate vocational or lower	**50%**	**40%**	**44%**	**54%**	**<u>83%</u>**	**<u>33%</u>**	**56%**
- via nearest fire exit	67%	50%	80%	62%	53%	62%	61%
- via other exit	33%	50%	20%	38%	47%	38%	39%
Higher vocational or academic	**50%**	**60%**	**56%**	**46%**	**<u>17%</u>**	**<u>67%</u>**	**44%**
- via nearest fire exit	42%	42%	69%	67%	25%	81%	40%
- via other exit	58%	58%	31%	33%	75%	19%	60%

The underlined figures are found to be significant different in the absolute validation analysis.

In all of the scenarios, the fraction of males is significantly larger in the tests in the virtual environment than in the real environment. Nevertheless, the results of a two-factor analysis of variance (ANOVA) show that there is no significant interaction effect of gender and environment on exit choice, F (1, 43) = 0.056, p = 0.814, η^2 = 0.001. Thus, gender has no significant influence on exit choice.

In the low exit sign scenario, a relatively small percentage (17%) of participants in the virtual environment had a higher vocational or academic educational level compared to the participants in the real environment (67%). This difference is significant (p<0.001). However, the two-factor ANOVA showed no interaction effect of education level and environment on exit choice, F(1, 43) = 1.926, p = 0.172. The small effect size (η^2 = 0.043) suggests that that the non-significant result arose from a genuine absence of a difference in the effect in the virtual and real environment. Thus, the educational level does not have a significant influence on exit choice.

Table 8.12. Personality of participants and exit choice

			Scenarios with smoke				
	Basic scenario (without smoke)		Smoke		Low exit sign		Reduced lighting
	VE	RE	VE	RE	VE	RE	VE
Personality	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**
No. of persons	24	20	23	39	23	24	23
BAS total	**26.5**	**29.2**	**27.8**	**27.4**	**29.0**	**27.0**	**30.0**
- via nearest fire exit	25.6	28.8	27.5	27.4	29.0	27.0	29.1
- via other exit	27.6	29.5	28.7	27.4	29.1	27.0	31.1
ACS attention	**54.7**	**50.2**	**60.0**	**57.1**	**58.7**	**52.5**	**53.8**
- via nearest fire exit	54.6	52.5	57.9	58.6	56.8	52.3	53.4
- via other exit	54.7	48.6	66.0	54.4	60.5	53.0	54.3
ACS switching	**31.6**	**27.6**	**35.5**	**34.0**	**35.8**	**30.1**	**32.0**
- via nearest fire exit	31.7	29.4	34.5	34.8	35.8	29.6	32.4
- via other exit	31.5	26.3	38.3	32.3	35.8	31.8	31.6
CERQ total	**46.8**	**47.1**	**46.1**	**45.9**	**46.1**	**52.0**	**46.6**
- via nearest fire exit	47.5	49.9	45.2	43.8	44.3	51.4	46.4
- via other exit	45.9	45.1	48.5	49.7	47.8	54.0	46.7

The underlined figures are found to be significant different in the absolute validation analysis.

There are several differences in the effects of personality traits. In a two-factor ANOVA test, no significant difference exists in choice between participants with a high or low 'ACS attention control', 'ACS switching' or 'CERQ total' score in the low exit sign scenario, nor between the participants with a high and low 'BAS total' score in the basic scenario. In the basic scenario, a significant difference in exit choice is found between participants with high and low 'ACS switching' scores ($p<0.05$), as the mean score in the real environment is relatively low (26.3) for the participants who evacuated via the main exit and relatively high (29.4) for the participants who evacuated via the nearest fire exit. In the virtual environment, the scores for 'ACS switching' are comparable for the two groups (exits), namely, 31.5 and 31.7 points. However, since there is no significant difference in exit choice between the real and virtual environment in the basic scenario, the difference in exit choice between participants with high and low 'ACS switching' scores is not considered relevant.

8.5.3 Exit choice motivations: Considerations

An explanation of the deviation from the assumption that if the exit signs are placed at floor level (low exit sign scenario) more participants tend to evacuate via the nearest fire exit than if the exit signs are placed at ceiling level (smoke scenario) can possibly be found in the difference in the considerations of the safest route: in the low exit sign scenario in the virtual environment, a relatively low percentage (53%) considered the safest route compared to in the real environment (91%), see Table 8.7. In the smoke scenario, about 69% of the participants in both environments considered the safest route, and in the basic scenario about 74% in both environments.

Table 8.13. Considerations and exit choice

			Scenarios with smoke				
	Basic scenario (without smoke)		Smoke		Low exit sign		Reduced lighting
	VE	RE	VE	RE	VE	RE	VE
No. of persons	24	20	23	39	23	24	23
Fastest route (yes)	**87%**	**87%**	**91%**	**63%**	**85%**	**95%**	**82%**
- via nearest fire exit	55%	61%	76%	67%	65%	78%	44%
- via other exit	45%	39%	24%	33%	35%	22%	56%
Fastest route (no)	**13%**	**13%**	**9%**	**37%**	**15%**	**5%**	**18%**
- via nearest fire exit	20%	0%	62%	64%	0%	0%	75%
- via other exit	80%	100%	38%	36%	100%	100%	25%
Shortest route (yes)	**74%**	**73%**	**74%**	**66%**	**74%**	**89%**	**82%**
- via nearest fire exit	59%	73%	88%	80%	71%	76%	44%
- via other exit	41%	27%	12%	20%	29%	24%	56%
Shortest route (no)	**26%**	**27%**	**26%**	**34%**	**26%**	**11%**	**18%**
- via nearest fire exit	20%	0%	37%	39%	14%	50%	75%
- via other exit	80%	100%	63%	61%	86%	50%	25%
Safest route (yes)	**75%**	**73%**	**70%**	**68%**	**53%**	**90%**	**73%**
- via nearest fire exit	61%	73%	77%	77%	50%	84%	56%
- via other exit	39%	27%	23%	23%	50%	16%	44%
Safest route (no)	**25%**	**27%**	**30%**	**32%**	**47%**	**10%**	**27%**
- via nearest fire exit	20%	0%	47%	42%	36%	0%	33%
- via other exit	80%	100%	53%	58%	64%	100%	67%
Familiar route (yes)	**65%**	**81%**	**61%**	**61%**	**63%**	**75%**	**73%**
- via nearest fire exit	27%	39%	71%	46%	25%	73%	38%
- via other exit	73%	61%	29%	54%	75%	27%	62%
Familiar route (no)	**35%**	**19%**	**39%**	**39%**	**37%**	**25%**	**27%**
- via nearest fire exit	100%	100%	87%	93%	83%	80%	83%
- via other exit	0%	0%	13%	7%	17%	20%	17%

Missing results: Basic scenario, 5 in RE and 1 in VE; Smoke scenario, 1 in RE; Low exit sign scenario, 4 in RE and 4 in VE.
The underlined figures are found to be significant different in the absolute validation analysis.

In the smoke scenario, 77% of the participants who considered the safest route evacuated via the nearest fire exit in both environments, which is in accordance with the assumption of exit choice when smoke blocks the route towards the main exit.

However, in the low exit sign scenario in the virtual environment, a relatively small percentage of the participants who considered the safest route evacuated via the fire exit (which is the safest route), namely, 50%, compared to 84% of the participants in the real environment. This result seems to be counterintuitive. A two-factor ANOVA was conducted to determine if the difference in exit choice between the participants who did and did not consider the safest route in the two test environments is significant.

The results of the two-factor ANOVA reveal a main effect for the consideration of the safest route in the low exit sign scenario, $F(1, 36) = 5.240$, $p = 0.028$, with a medium effect size ($\eta^2 = 0.127$). However, the ANOVA did not reveal an interaction effect of the consideration of the safest route and the environment on the exit choice, $F(1, 36) = 4.023$, $p = 0.052$. The moderate effect size ($\eta^2 = 0.101$) suggests that a difference may exist, but that it could not reach statistical significance due to an insufficient sample size. This indicates that the consideration of the safest route correlates with exit choice, though the effect of the consideration of the safest route is probably significantly different between the virtual and real environments.

Table 8.14. Considerations and education

	Basic scenario (without smoke)		Scenarios with smoke: Smoke		Scenarios with smoke: Low exit sign		Scenarios with smoke: Reduced lighting
	VE	**RE**	**VE**	**RE**	**VE**	**RE**	**VE**
No. of persons	24	20	23	39	23	24	23
Intermediate vocational or lower	**50%**	**40%**	**44%**	**54%**	**<u>83%</u>**	**<u>33%</u>**	**57%**
- Safest route (yes)	83%	100%	60%	70%	53%	100%	67%
- Safest route (no)	17%	0%	40%	30%	47%	0%	33%
Higher vocational or academic	**50%**	**60%**	**56%**	**46%**	**<u>17%</u>**	**<u>67%</u>**	**44%**
- Safest route (yes)	67%	56%	77%	67%	50%	87%	80%
- Safest route (no)	33%	44%	23%	33%	50%	13%	20%

The underlined figures are found to be significant different in the absolute validation analysis.

A further analysis was conducted to explore if the possible difference in the effect of the consideration of the safest route in exit choice correlates with the significant difference in the education level in the low exit sign scenario, see Table 8.14. However, the ANOVA did not reveal an interaction effect of the education level and the environment on the consideration of the safest route, $F(1, 36) = 0.101$, $p = 0.752$, $\eta^2 = 0.003$. Thus, the difference in education level in the low exit sign scenario had no significant influence on the consideration of the safest route.

Decisive factor for exit choice

Prior to the question on their considerations, the participants were asked about the decisive factor for exit choice. It was an open question and the answers were labelled afterwards. There were eight factors that were mentioned by two or more participants, see Table 8.15.

Table 8.15. Decisive factor for exit choice

	Basic scenario (without smoke)		**Scenarios with smoke**				
			Smoke		**Low exit sign**		**Reduced lighting**
	VE	**RE**	**VE**	**RE**	**VE**	**RE**	**VE**
No. of persons	24	20	23	39	23	24	23
Green exit signs	29%	25%	39%	49%	39%	50%	44%
Familiar route	25%	30%	17%	21%	35%	25%	22%
Fastest route	8%	5%	17%	8%	9%	0%	9%
Go to reception	8%	5%	0%	3%	4%	0%	4%
Escape route map	0%	5%	0%	3%	0%	8%	0%
Shortest route	0%	5%	4%	5%	0%	0%	0%
Towards fire exit	0%	0%	4%	3%	4%	0%	0%
Earlier walked route	4%	5%	4%	0%	0%	0%	0%
Other factor	25%	20%	13%	10%	9%	17%	22%

There are two decisive factors that were mentioned the most by the participants, namely, 'green exit signs' and a 'familiar route'. There is no significant difference between these top two considerations. One of the decisive factors that was mentioned by a total of five participants was the 'message: go to the reception'. This is noteworthy since there was no message to go to the reception, though several participants declared to have based their exit choice on that non-existent message.

8.5.4 *Exit choice motivations: Fire safety attitude*

The term 'fire safety attitude' refers to actions that are related to an awareness of fire safety measures in the surroundings and an accurate use of them. For example, if a person has seen the green exit signs, made use of them and followed the route that was marked by the signs, then the person has an adequate fire safety attitude. In this study, a fire safety attitude was indicated by three aspects, namely, the use of exit signs, the use of escape route maps and the inspection of the escape route. Therefore, in the questionnaire the participants were asked if they had made use of the exit signs, if they had inspected the escape route before the evacuation and if they had made use of the escape route maps. The results are presented in Tables 8.16, 8.17 and 8.18.

Use of exit signs
In the questionnaire, the participants were asked if they had made use of the exit signs. Many participants declared that they had made use of the exit signs during their evacuation: about 72% in both environments in the smoke scenario and about 60% in the low exit sign scenario. In the basic scenario, there is a difference in the fraction of participants who declared the use of the exit signs between the real and virtual environments, although it is not significant.

Table 8.16. Safety behaviour, use of exit signs

			Scenarios with smoke				
	Basic scenario (without smoke)		**Smoke**		**Low exit sign**		**Reduced lighting**
	VE	**RE**	**VE**	**RE**	**VE**	**RE**	**VE**
No. of persons	24	20	23	39	23	24	23
Missing results	29%	20%	13%	15%	30%	17%	35%
Use of exit signs	**57%**	**45%**	**74%**	**69%**	**57%**	**62%**	**48%**
- via nearest fire exit	79%	78%	88%	67%	69%	93%	82%
- via other exit	21%	22%	12%	33%	31%	7%	18%
No use of exit signs	**13%**	**35%**	**13%**	**15%**	**13%**	**21%**	**17%**
- via nearest fire exit	33%	14%	67%	67%	0%	40%	25%
- via other exit	67%	86%	33%	33%	100%	60%	75%

There is no large difference in the declared use of exit signs in the low exit sign scenario between the two environments, though the fraction of participants who declared the use of exit signs is relatively low in the virtual environment. Moreover, the fraction of the participants who declared the use of exit signs that really made use of the nearest fire exit is also relatively low, whereas in the real environment nearly all of the participants who declared the use of exit signs evacuated via the nearest fire exit, compared to about two third of those in the virtual environment.

The impact of fire safety attitude was also analysed. The results of the two-factor ANOVA revealed a main effect for the use of exit signs on the exit choice in the low exit sign scenario, $F(1, 32) = 14.485$, $p = 0.001$, with a large effect size ($\eta^2 = 0.312$). However, the ANOVA showed no interaction effect between the use of exit signs and environment on exit choice, $F(1, 32) = 0.244$, $p = 0.625$. The small effect size ($\eta^2 = 0.008$) suggests that the non-significant result arose from a genuine absence of a difference in this effect on exit choice between the virtual and real environments. The results indicate that the difference in the use of the exit signs had a significant influence on the exit choice in the real environment, though it had no significant influence on exit choice in the virtual environment. No explanation can be found for the difference in the degree of this influence between the two environments.

Prior inspection of the escape route

The fraction of participants in the virtual hotel that declared to have inspected the escape route before the evacuation is comparable to the fraction of participants in the real hotel in the basic scenario (38% and 35%) and the low exit sign scenario (52% and 54%).

Table 8.17. Safety behaviour, prior inspection of escape route

	Basic scenario (without smoke)		Scenarios with smoke: Smoke		Scenarios with smoke: Low exit sign		Scenarios with smoke: Reduced lighting
	VE	**RE**	**VE**	**RE**	**VE**	**RE**	**VE**
No. of persons	24	20	23	39	23	24	23
Missing results	0%	0%	0%	13%	0%	0%	0%
Inspection	**38%**	**35%**	**70%**	**28%**	**52%**	**54%**	**48%**
- via nearest fire exit	56%	86%	82%	73%	58%	92%	54%
- via other exit	44%	14%	19%	27%	42%	8%	46%
No inspection	**62%**	**65%**	**30%**	**59%**	**48%**	**46%**	**52%**
- via nearest fire exit	53%	23%	57%	65%	36%	54%	50%
- via other exit	47%	77%	43%	35%	64%	46%	50%

For the smoke scenario, there is a significant difference in the fraction of participants that had, or had not, inspected the escape route ($p<0.01$); however, the prior inspection did not have a significant influence on exit choice in either environment, $F(1, 53) = 0.372$, $p = 0.545$, $\eta^2 = 0.007$.

There is no large difference in the declared prior inspection of the escape route in the low exit sign scenario in the two environments, though the fraction of the participants who declared to have inspected the escape route that really made use of the nearest fire exit is relatively low in the virtual environment (58%) compared to the real environment (92%). This is a significant difference: the results of the two-factor ANOVA reveal a main effect for the use of exit signs on the exit choice in the low exit sign scenario, $F(1, 43) = 4.922$, $p = 0.032$, with a moderate effect size ($\eta^2 = 0.103$). However, the ANOVA did not reveal an interaction effect of the prior inspection of the escape route and environment on the exit choice, $F(1, 43) = 0.344$, $p = 0.561$. The small effect size ($\eta^2 = 0.008$) suggests that the non-significant result arose from a genuine absence of a difference in this effect on exit choice between the virtual and real environments. Thus, there is a significant correlation between the prior inspection of the escape route and the exit choice in the real environment, though there is no significant correlation found in the virtual environment. There is no explanation for the difference in the presence of a correlation between the real and virtual environments.

Use of escape route maps

The fraction of participants in the virtual hotel that declared to have made use of the escape route maps before or during their evacuation is comparable to the fraction of participants in the real hotel in the basic scenario (21% and 20%) and the smoke scenario (22% and 26%), see Table 8.18.

Table 8.18. Safety behaviour, use of escape route maps

			Scenarios with smoke				
	Basic scenario (without smoke)		Smoke		Low exit sign		Reduced lighting
	VE	RE	VE	RE	VE	RE	VE
No. of persons	24	20	23	39	23	24	23
Missing results	0%	20%	0%	2%	0%	0%	0%
Use of maps	**21%**	**20%**	**22%**	**26%**	**17%**	**42%**	**9%**
- via nearest fire exit	80%	100%	80%	70%	75%	90%	50%
- via other exit	20%	0%	20%	30%	25%	10%	50%
No use of maps	**79%**	**60%**	**78%**	**72%**	**83%**	**58%**	**91%**
- via nearest fire exit	47%	33%	72%	61%	42%	64%	52%
- via other exit	53%	67%	28%	39%	58%	36%	48%

There is a difference in the use of escape route maps in the low exit sign scenario between the real and virtual environments, though it is not significant. In addition, a large fraction of the participants who declared the use of the escape route maps evacuated via the nearest fire exit in both environments. Thus, there is no indication that the difference in exit choice in the low exit sign scenario correlates with the use of the escape route maps.

8.5.5 Exit choice motivations: Perception of the situation

After the evacuation test, the participants were asked about their perception of the situation. Two types of perceptions were assessed, namely, their emotions regarding the evacuations and their perceptions of their physical surroundings. The participants scored their perceptions on a scale from 1 (low) to 10 (high). The findings on their perceptions of the situation are presented in Tables 8.19 and 8.20.

The results of the T-test show that the grades on the perceptions of the ease of finding the way and of the clearness of the layout are significantly lower in the virtual environment in all three scenarios. Although the two-factor ANOVA shows that the perception of the ease of finding the way had no significant influence on the exit choice in both environments, $F (1, 135) = 0.795$, $p = 0.575$, $\eta^2 = 0.034$. The ANOVA also showed no interaction effect between the clear organization of the lay out and the environment on exit choice, $F (1, 130) = 0.797$, $p = 0.606$, $\eta^2 = 0.047$. Based on the small effect sizes, the non-significant result arose from a genuine absence of differences. Thus, there is no significant correlation between the perceptions of the physical surroundings and the exit choice in both test environments.

In all three scenarios, the sense of emergency is significantly stronger in the virtual environment. This confirms the assumptions that in ADMS-BART people are faced with the phenomenon of fire in a realistic way and that experimental research in a virtual setting will be more convincing than experimental research in a real world setting. In addition, the assumption that people with a high sense of emergency are more likely to evacuate via the nearest fire exit is true for nearly all scenarios, except for the low exit sign scenario in the real environment. However, in the real environment the sense of emergency of the participants who evacuated via the nearest fire exit (3.8) is not significantly higher than the sense of emergency of those who evacuated via another exit (4.0). This implies that there is no reason to assume that the higher sense of emergency in the real environment had a strong influence on the exit choice. In addition, in the virtual environment

Table 8.19. Perceptions on the physical surroundings

	Basic scenario (without smoke)				Scenarios with smoke: Smoke				Scenarios with smoke: Low exit sign			
	N	Mean	SD	Sign. (p)	N	Mean	SD	Sign. (p)	N	Mean	SD	Sign. (p)
Ease of way finding												
- virtual environment	24	**6.4**	2.4	**<0.01**	23	**6.3**	2.1	**<0.01**	23	**6.1**	2.2	**<0.01**
- real environment	20	**8.4**	1.2		38	**7.9**	1.7		24	**8.1**	1.5	
Clear organization of lay out												
- virtual environment	24	**5.3**	2.3	**<0.001**	23	**5.8**	2.2	**<0.01**	23	**5.6**	2.1	**<0.01**
- real environment	20	**8.0**	1.4		38	**7.4**	1.8		21	**7.4**	1.9	

Table 8.20. Emotions

	Basic scenario (without smoke)				Scenarios with smoke: Smoke				Scenarios with smoke: Low exit sign			
	N	Mean	SD	Sign. (p)	N	Mean	SD	Sign. (p)	N	Mean	SD	Sign. (p)
Sense of good result												
- virtual environment	24	**7.8**	2.0		23	**8.3**	1.2		23	**7.5**	2.6	
- real environment	20	**6.9**	2.2		39	**7.7**	1.5		24	**8.0**	1.4	
Sense of haste												
- virtual environment	24	**7.7**	1.8		23	**7.5**	1.3	**<0.001**	23	**7.5**	1.3	**<0.05**
- real environment	16	**6.5**	2.2		39	**6.6**	2.2		22	**6.1**	2.8	
Sense of time pressure												
- virtual environment	24	**6.8**	2.0		23	**5.9**	2.2		23	**6.3**	2.1	
- real environment	20	**6.0**	2.4		39	**6.1**	2.5		23	**5.9**	2.8	
Sense of emergency												
- virtual environment	24	**5.8**	1.8	**<0.05**	23	**6.3**	2.3	**<0.01**	23	**6.6**	1.8	**<0.001**
- real environment	20	**4.3**	1.9		39	**4.2**	2.4		22	**4.0**	2.6	
Sense of stress												
- virtual environment	24	**4.6**	1.8		23	**4.7**	2.6		23	**5.0**	2.0	**<0.05**
- real environment	16	**4.0**	2.0		38	**3.8**	2.1		23	**3.6**	2.4	

there is no significant difference in the level of the sense of emergency of the participants who evacuated via the nearest fire exit (6.9) compared to those who evacuated via another exit (6.3), see Table 8.21.

Table 8.21. Emotions by exit choice, in virtual (VE) and real environment (RE)

	Basic scenario (without smoke)			Scenarios with smoke					
				Smoke			Low exit sign		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Sense of haste (VE)									
- via nearest fire exit	13	7.9	1.5	17	7.8	1.3	11	7.6	1.4
- via other exit	11	7.6	2.1	6	6.8	1.2	12	7.5	1.2
Sense of haste (RE)									
- via nearest fire exit	8	7.1	2.2	25	6.6	2.3	17	5.8	2.6
- via other exit	8	5.9	2.0	14	6.6	2.3	6	7.2	3.6
Sense of emergency (VE)									
- via nearest fire exit	13	5.9	1.8	17	6.7	2.1	11	6.9	1.5
- via other exit	11	5.6	1.9	6	5.0	2.6	12	6.3	2.1
Sense of emergency (RE)									
- via nearest fire exit	9	4.3	1.9	25	4.4	2.5	17	3.8	2.1
- via other exit	11	4.3	2.0	14	4.0	2.3	5	4.8	3.9
Sense of stress (VE)									
- via nearest fire exit	13	4.2	1.7	17	4.8	2.5	11	4.5	1.8
- via other exit	11	5.0	1.8	6	4.5	3.0	12	5.5	2.2
Sense of stress (RE)									
- via nearest fire exit	8	3.4	2.3	24	3.7	1.9	17	3.5	2.2
- via other exit	8	4.6	1.6	14	3.9	2.6	6	3.7	3.1

The two-factor analysis of variance (ANOVA) shows that the difference in the level of the sense of emergency for the two exit choice options is not significant between the two test environments in the basic scenario, nor in the smoke scenario. However, there is a strong interaction effect in the low exit sign scenario, $F (1, 29) = 2.673$, $p = 0.042$, $\eta^2 = 0.315$. This indicates that the effect of the level of the sense of emergency on the exit choice is significantly different between the two test environments. In Table 8.19, it can been seen that there is a strong difference in the sense of emergency between the participants who evacuated via the nearest fire exit or another exit in the real environment, but there is no strong difference in the virtual environment.

In all three scenarios, the sense of stress is also stronger in the virtual environment than in the real environment, though it is only significant in the low exit sign scenario. Furthermore, the sense of stress is lower for the participants who evacuated via the nearest fire exit than for the participants who evacuated via another exit in nearly all of the scenarios in both environments, except for the smoke scenario in the virtual environment for which the level of stress is slightly higher. Nevertheless, the two-factor analysis of variance (ANOVA) shows that the difference in the level of the sense of stress for the two exit choice options in the low exit sign scenario is not significantly different between the two environments. This implies that there is no reason to assume that the higher level of stress in the virtual environment influenced the exit choice.

In addition, the sense of haste in all three scenarios is also stronger in the virtual environment, though the difference in the sense of haste between the two environments is only significant in the smoke scenario and in the low exit sign scenario. Furthermore, the sense of haste is higher for the participants who evacuated via the nearest fire exit than for the participants who evacuated via another exit in nearly all the scenarios in both environments (VE and RE), except for the low exit sign scenario in the real environment. Nevertheless, the two-factor analysis of variance (ANOVA) shows that the difference in the level of the sense of haste between the two exit choice options is not significant between the two environments in the low exit sign scenario, $F(1, 30) = 1.016$, $p = 0.425$. The large effect size ($\eta^2 = 0.145$), though, suggests that perhaps a difference exists, but that it could not reach statistical significance due to an insufficient sample size. Thus, the level of the sense of haste possibly correlates with exit choice in the both environments. Nevertheless, there is still no clear explanation for the finding that the exit choice in the low exit sign scenario in the virtual environment deviates from the assumption that if the exit signs are placed at floor level (low exit sign scenario) more participants tend to evacuate via the nearest fire exit than if the exit signs are placed at ceiling level (smoke scenario).

8.5.6 Discussion and conclusions about the possible explanatory variables

The further analysis of factors that could have possibly influenced exit choice shows that gender, educational level and the examined personality traits are not significantly correlated with exit choice. Furthermore, the difference in education level in the low exit sign scenario had no significant influence on the consideration of the safest route. This indicates that the profile of occupants did not have a strong influence on consideration of the safest route or on exit choice.

There is no indication that the difference in exit choice in the low exit sign scenario correlates with the use of the escape route maps. Furthermore, there is no significant correlation between the perceptions of the physical surroundings and the exit choice in either test environment in all three scenarios.

The following variables correlate with exit choice in the low exit sign scenario in the real environment, but not in the virtual environment:

- Consideration of the safest route
- Use or absence of use of the exit signs
- Prior inspection of the escape route
- Sense of emergency

The differences in the effects are found to be significantly different between the real and virtual environments. In addition, the direction of the effect of the sense of emergency deviates in the real environment from all other scenarios (VE and RE). The mean grade for the sense of emergency of the participants who evacuated via the nearest fire exit is lower than the mean grade of the participants who evacuated via another exit.

There are some differences between the findings in the real and virtual environment, though only in the low exit sign scenario. There is no clear reason for the differences found. Thus, further research is needed on the low exit sign scenario.

Evidently, experimental research in the virtual setting of ADMS-BART is more convincing than experimental research in a real world setting, as some vital emotions are significantly stronger in the tests in the virtual environment compared to the tests in the real environment: the sense of emergency is stronger in all three scenarios, the sense of haste is stronger in the scenarios with perceptible smoke. This also suggests that in the serious game ADMS-BART people are faced with the phenomenon of fire in a more realistic way than in an experimental situation in a real world surrounding.

8.6 STEP 4: Assessment of a potential influence of game control skills

8.6.1 Introduction

In this section, the results of the assessment of the potential influence of the participants' level of game control skills after training on the demonstrated behaviour in the virtual environment are presented.

8.6.2 Exit choice

The mean scores for the level of (self-assessed) game control skills were tested for the groups of participants who evacuated via the main exit (group 1) or the nearest fire exit (group 2). The test was conducted with the results of the participants in all the three of the scenarios bulked together. In total, 24 participants evacuated via the main exit and the mean score for their level of game control skills is 6.5. A total of 36 participants evacuated via the nearest fire exit and the mean score for their level of game control skills is 7.1.

The two-factor ANOVA did not reveal a main effect of game control skills on the exit choice, $F(1, 57) = 0.873$, $p = 0.533$, with a moderate effect size ($\eta^2 = 0.097$). Thus, there is no evidence to conclude that the level of game control skills was different for the participants who evacuated via the nearest fire exit or via another exit.

8.6.3 Route deviation

It is assumed that participants with a relatively low level of game control skills are more likely to deviate from the shortest egress route than the participants with a relatively high level of game control skills. The route deviation is analysed in two aspects, namely, the longer distance walked and the exposed turning behaviour. The mean scores for the level of game control skills were tested for the group of participants who did not turn to deviate from their initial route during their evacuation (group 1) and for the group of participants who altered their route (group 2). The test was conducted with the results of the participants in all the three scenarios together. In total, 17 participants turned to deviate from their initial route. The mean score for game control skills is 7.0 for this group. The other 43 participants that did not turn have a mean score of 6.8 for game control skills.

The two-factor ANOVA did not reveal a main effect for game control skills on the route deviation, $F(1, 57) = 0.533$, $p = 0.806$, $\eta^2 = 0.061$, nor the turning behaviour, $F(1, 57) = 1.265$, $p = 0.284$, $\eta^2 = 0.134$. Since the effect size for the longer walked distance is small ($\eta^2 = 0.061$), the non-significant result arose from a genuine absence of difference. However, the effect size for the exposed turning behaviour is large, which means that the means of game control skills are probably not different for the participants who turned to deviate from their initial route during their evacuation or did not change course.

8.6.4 Perception of situation

In the low exit sign scenario, there is a significant difference ($p<0.05$) in the level of stress between the real and virtual environment. The stress level is 3.6 points in the real environment and 5.0 points in the virtual environment. The assumption is that a low level of game control skills will result in a higher sense of stress during the evacuation exercise in the virtual environment. However, the two-factor ANOVA showed no main effect for the level of game control skills on the perceived level of stress, $F(1, 15) = 1.024$, $p = 0.427$, $\eta^2 = 0.214$. This suggests that a difference may exist, but that it is not statistically significant due to an insufficient sample size. Nevertheless, there is no evidence to conclude that the means of game control skills are different for the participants who perceived a high or low level of stress.

8.6.5 Discussion and conclusions on the influence of game control skills

Several variables that may have been influenced by the level of game control skills were analysed, namely, the exit choice, the route deviation and the perception of the situation. The results of the analysis indicate that there is no evidence to conclude that the means of game control skills are different for different exit choices, decisions to alter routes or perceived levels of stress. Moreover, it can be claimed that the non-significant result for the effect of game control skills on the length of distance walked arose from a genuine absence of difference. This indicates that the behaviour of participants in ADMS-BART was probably not influenced by their level of game control skills. Moreover, as revealed in the user convenience test (Section 6.6.4), ADMS-BART is easy to control given that the ease of controlling the game is judged to be high (7.0-7.7 points). This implies that ADMS-BART is suitable for participants with a high level of game control skills, as well as for participants with a low level of game control skills.

8.7 Summary and conclusions

8.7.1. Validation steps

To validate ADMS-BART four validation steps were taken.

- First, a comparison was conducted on the group compositions between the real and virtual environments.
- The second step consisted of the absolute-validation analysis. Absolute validity refers to the numerical correspondence between behavioural data in the simulation and the real environment.
- The third step consisted of the relative-validation analysis. Relative validity refers to the correspondence between effects of different variations in the experimental conditions. The effects were analysed with respect to similarity in magnitude and direction in the real and virtual environments.
- The fourth step consisted of an assessment of the potential influence of game-control skills on the demonstrated behaviour in the virtual environment.

The conclusions of the validation analysis are presented in the following sections.

8.7.2. Comparison of group compositions

Three aspects were evaluated, namely, the profile (gender, age, and educational level) and the personality of the participants, the level of prior knowledge of the participants (prior fire experience and safety trainings) and the starting positions of the tests.

Conclusion 8.1: The following factors were found to be significantly different between the virtual and real environments:

- The fractions of males and females in all three scenarios
- Personality traits: two traits in the basic scenario and three traits in the low-exit-sign scenario
- Educational level in the low–exit-sign scenario

In comparable studies on building evacuation, typically details are only provided on the gender and age of the participants.

8.7.2. Validation analysis (steps 2 and 3)

The absolute-validation analysis revealed that the use of ADMS-BART can be considered valid for most-examined aspects such as exit choice and walking distance. However, a significant difference was found in the exit choices in the low-exit-sign scenario. In the virtual environment, it deviated from the assumption that if the exit signs were placed at floor level (low-exit-sign scenario) more participants would evacuate via the nearest fire exit than if the exit signs were placed at ceiling level (smoke scenario). This finding is counterintuitive, thus a further analysis is needed. Nevertheless, absolute validity is not a necessary requirement for a simulator to be useful as a research tool.

Conclusion 8.2: ADMS-BART is not intended to be suitable for research on movement speed during fire evacuation, as the measured movement speed in the virtual hotel was based on four fixed walking velocities (running, walking, crawling, and standing).

In the relative-validation analysis two types of impact were analysed, namely, the impact of smoke on exit choice and the impact of the location of the exit signs on exit choice. Based on the results of the relative-validation analysis there was no reason to assume that the effect of smoke is different in the virtual and real environments. On the other hand, the effect of the location of the exit signs was found to be different in the virtual and real environments. This difference was probably due to an inconsistency in the low-exit-sign scenario, which already had been found in the absolute-validation analysis.

Conclusion 8.3: The use of ADMS-BART can be considered valid as a research tool for studying wayfinding behaviour during fire evacuation in a non-smoky situation.

Conclusion 8.4: The use of ADMS-BART can be considered valid as a research tool for studying the influence of smoke on way-finding during fire evacuation, as there is no reason to conclude that the effect of smoke is different in the virtual and real environments.

Conclusion 8.5: There is an indication that the effect of the location of the exit signs may be different in the virtual and real environments.

> There is no significant difference in exit choice between the smoke scenario and the low-exit-sign scenario in the real environment, while there is significant effect in the virtual environment. However, the direction of the effect in VE is opposed to the direction in RE, and moreover, the effect is counterintuitive.

8.7.3. Further analysis on possible explanatory variables

A further analysis was conducted to explore possible clarifications for the significant difference in exit choice in the low-exit-sign scenario. In this further analysis the possible influence of group compositions was analysed, as some significant differences in the group compositions had been found between VE and RE. The aspects of the participants profile that were analysed were:

- Gender
- Educational level
- Personality traits (ACS attention, ACS switching and CERQ total)

The possible influence of significant different exit choice motivations and of the perception of the situation between VE and RE were analysed as well. The rationale for the analysis of these possible influences is the theory that an occupant's fire response performance is influenced by their perceptions of the situation and of their motivations for their actions. The motivations and perceptions that were analysed were:

- The considerations of the fastest route
- The considerations of the safest route
- The decisive factor for exit choice
- The fire safety attitude (indicated by the use of exit signs, the use of escape route maps and the prior inspection of the escape route)
- The perception of the physical surroundings (opinions on the ease of wayfinding and clear organisation of lay out)
- The experienced emotions during the evacuation (the senses of haste, emergency and stress)

The analysed aspects of the participants' profile and most of the analysed aspects of the participants' motivations and perceptions did not have a significant influence on exit choice in the low-exit-sign scenarios in both environments. The influences of four variables, however, were found to be significantly different in the two environments.

Conclusion 8.6: In the low-exit-sign scenario there were differences between the real and virtual environments in the influence of four variables of the participants' motivations and perception on the exit choice. These differences cannot be explained.

> The following variables were correlated with exit choice in the low-exit-sign scenario in the real environment but not in the virtual environment:
> - Consideration of the safest route
> - Presence or absence of use of exit signs
> - Prior inspection of the escape route
> - Sense of emergency

In general the participants' senses of haste, time pressure, emergency and stress during their evacuation were stronger in the virtual environment compared to the real environment. This is true for all three scenarios (basic, smoke and low-exit-sign scenario).

Conclusion 8.7: There are indications that people who are tested in the ADMS-BART serious game are faced with the fire phenomenon in a more realistic way than in an experimental situation in real-world surroundings.

> Evidently, it was found that an experimental study in the virtual setting of ADMS-BART was more convincing than an experiment in a real-world setting, as some vital emotions, namely the sense of emergency, the sense of haste and the sense of stress, were significantly stronger in the tests in the virtual environment than in the tests in the real environment.

8.7.4. Assessment of the potential influence of game-control skills

The fourth step of the validation analysis consisted of an assessment of the potential influence of game-control skills on the demonstrated behaviour in the virtual environment.

Conclusion 8.8: ADMS-BART can be considered suitable for participants with a high level of game-control skills as well as for participants with a low level of game-control skills.

> The assessment revealed that the behaviour of participants in ADMS-BART was probably not influenced by their level of game-control skills. Thus, ADMS-BART can be considered suitable for participants with a high level of game-control skills as well as for participants with a low level of game-control skills.

8.7.5. Closing considerations

There is no reason to assume that the behaviour levels in the virtual environment would be more optimistic than the behaviour levels in a real test environment, as the perceptions on the ease of wayfinding and on the clear organisation of the layout were significantly lower in the tests in ADMS-BART. Thus the probability of a too positive evaluation of innovative safety measures for wayfinding during fire evacuation when tested in ADMS-BART is likely to be trivial.

As there is no significant difference between the results of the tests in the real environment and in the virtual environment in the basic scenario and the smoke scenario, it can be stated that the results of tests with the serious game at daytime come close to the behaviour of participants in a real world situation at night.

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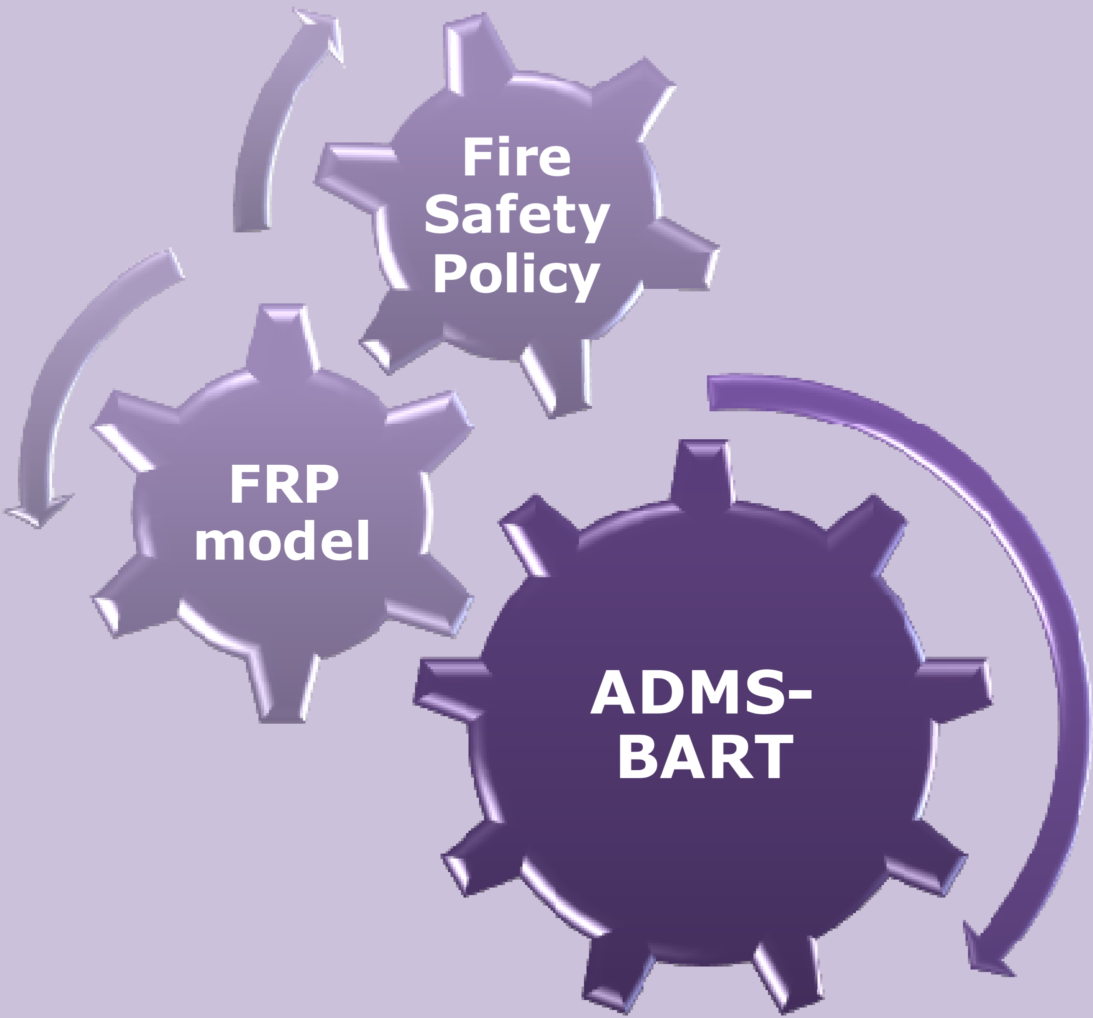


Arriving at one goal
is the starting point to another

John Dewey (1859 - 1952)

Chapter 9

Summary with Conclusions and Recommendations

9.1 Introduction

The most crucial aspect of a building's safety in the face of fire is the possibility for safe escape. An important precondition is that the building's fire safety facilities enable independent and adequate fire response performance of the building's occupants in the case of fire. In practice, it appears that the measures currently required by law do not always provide the support that people in burning buildings need, as over the centuries a gap has arisen between fire safety policy and the technological as well as human aspects, which actually determine fire safety. Additionally, several assumptions in current (Dutch) policy are found to be inconsistent with the knowledge in the literature. Consequently, to bring fire safety measures into line with occupants' needs during an incident, understanding how individuals behave in the case of fire and fire evacuation is essential. To achieve this, it is recommended that the scientific knowledge available from the field of psychonomics should be utilised. Psychonomics describes an approach to psychology that aims at discovering the laws that govern the workings of the mind. These laws lead to an understanding of how people process information. The primary concern of fire safety psychonomics is with the occupants' perception of the fire and the building environment.

The implementation of the psychonomic approach is achievable by using an assessment system based on fire safety engineering principles. By using this assessment system the required fire safety measures for a building's design can be engineered with three scenarios in mind, i.e., the fire scenario (FS), the fire repression scenario (FRS) and the occupant response scenario (ORS). To predict a reasonable occupant response scenario, new data are needed on evacuation behaviour in several surroundings and conditions. In the case of fire evacuation, the ease of wayfinding (toward a fire exit) is very important for survival, as additional psychic stress caused by wayfinding problems can impair cognitive processes and the person's response. Wayfinding can be described as the process of spatial orientation and spatial problem solving, wherein spatial and environmental information is used as a communication device for navigation to find our way in the building environment. Although some aspects of wayfinding during evacuation have been investigated, it is not discussed at great length. In particular, there is little insight into how persons find their escape route and how this process of wayfinding can be supported with layout and design measures.

To collect new data on human behaviour in a fire, experimental research can be conducted. In experimental research on human behaviour in a fire, it is reasonable to do the research in an environmental setting that is comparable to a real fire situation. However, to guarantee the safety of participants in experimental research, it is hardly safe to expose people with the phenomenon of fire in a realistic way. The confrontation with real fire incident stressors is present in case studies, although this type of research is controlled by the incident situation and not by a certain need of knowledge. In a serious game, it is possible to realistically confront people with the phenomenon of fire without exposing them to the extreme health risk of a real fire. For that reason, the application of a serious game in behavioural research is expected to be a valuable supplement to the existing research methods. This new research method is assumed to be suitable to stipulate the necessary fire safety measures in a building design based on psychonomics.

A serious game is defined as a game that uses interactive simulation by means of computer technology. Interactive simulation is the representation of the role of a human, the environment, or both, which will change over time if actions are or are not taken by the player. Regardless of the media involved, serious games are aimed at engendering a variety of cognitive, sensory, and emotional experiences in the players.

Textbox 9.1.

The primary aim of the research is the validation of a new research method that uses serious gaming. The new research method consists of an analysis model to systematically study the fire response performance of people in buildings (FRP-model), and of a virtual environment wherein the human behaviour can be comprehensively studied, namely the serious game ADMS-BART. After the use of ADMS-BART is validated as a research tool, a multitude of experiments can be carried out for deciding which building design fits best with actual human behaviour during fires.

The new research method has been developed to obtain insight into evacuation behaviour and the effect of the building design on that evacuation behaviour, in particular on wayfinding. The additional aim of the research is, therefore, the following:

- To obtain insight into human behaviour in fires, particularly the intentions on which the route choice of evacuees are based.
- To study the influence of aspects of human factors, building factors and fire factors on the fire response performance, in particular the wayfinding performance.

9.2 Results of the literature review

9.2.1 Synopsis

The field of scientific research into human behaviour in a fire is relatively new, although numerous studies have been conducted on this issue since the start of the 20th century and are continuing. Nevertheless, at present our knowledge of occupants' performances when confronted with fire is still very limited. Yet, in terms of optimising fire safety policy, it is important to understand why certain incidents have led to many victims or why a seemingly disastrous event resulted in very few casualties. These questions were the starting point for a literature review, which aimed to identify the critical factors that influence fire response performance.

Fire response performance is an individual's ability to perceive and interpret signs of danger, to make decisions and to take actions aimed at surviving a fire.

Textbox 9.2.

The definition of fire response performance is process related and is based upon an understanding of evacuation. This process is divided into three activities and stages:
- Awareness of danger by external stimuli (cue validation period)
- Validation of, and response to, danger indicators (decision-making period)
- Movement to/refuge in a safe place (movement period)

Incident analyses have shown that there is a connection between a delayed evacuation and a high number of fire deaths or injuries, particularly in residential buildings and hotels. To determine which measures would hasten the time taken to make decisions and which steps would lead to people choosing the correct escape routes, we need information about the perceptions, intentions and motives of those who are trying to escape from a fire. On reviewing the literature on the critical factors that determine fire response performance, it is clear that occupants' behaviour interacts with the conditions of the surrounding environment and the fire safety measures in place in the building. Generally speaking, three groups of factors determine the degree of fire response performance in the event of fire in a building. These are as follows:

- Fire characteristics
- Human characteristics
- Building characteristics

These three groups of factors are subdivided into several detailed characteristics.

9.2.2 Conclusion and recommendation of the literature review

Conclusion 1: The existing knowledge on fire response performance has to be increased by further research:

- There is need for further knowledge of the influence of surrounding factors (fire situation, building design, and social factors) on occupants' fire response performance. In particular, there is little insight into how persons find their escape route, and how this process can be supported with layout and design measures has been hardly examined.
- Regarding fire safety policy, there is need for further knowledge on measures that would have a positive influence on the fire response performance. To determine which measures would hasten the time taken to make decisions and which steps would lead people to choose the correct escape routes, we need information about the perceptions, intentions and motives of those who are trying to escape from a fire.

  Recommendation 1: The starting point for fire prevention measures should be the psychonomic interaction between the characteristics of a building and the human behaviour in fire.

9.3 Case study with use of the FRP model

9.3.1 Synopsis

Based on the literature review, the level of fire response performance is influenced by three groups of factors, namely the fire characteristics, the human characteristics and the building characteristics. The three groups of factors, and their sub-factors, are brought together in the fire response performance model (FRP model). With that, the FRP model gives an overview of the critical factors that determine the fire response performances of the occupants. The model takes into account the interaction between human and building characteristics as well as the interaction between human and fire characteristics and the interaction between fire and building characteristics. The FRP model is presented in Figure 9.1.

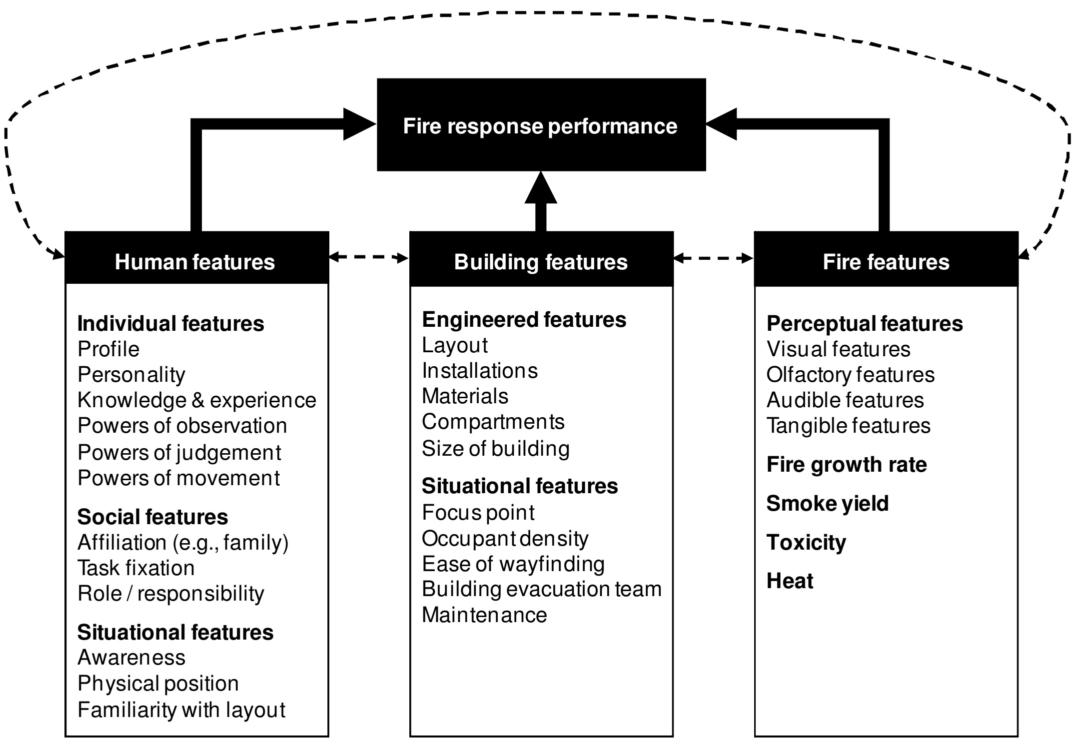


Figure 9.1. Fire response performance model (FRP model)

To make the model applicable for further research on human behaviour in fire, the model has been modified into a qualitative analysis model. Therefore, the expected influence of the critical factors is determined based on existing literature. Additionally, the application of the qualitative FRP model as a priori theory for case studies on fire safety psychonomics has been verified by conducting a case study on the fire response performance in a fire in a football stadium.

The case study revealed that the predictions in the FRP model appear to represent the features that played a role in a football stadium fire. Only one extra level of influence must be added to the feature of heat, which is the positive influence of a moderate heat level; this, however, is considered to be a minor modification of the model.

The case study also revealed that the preservation of safety regulations plays a vital role in the occurrence of an incident. If people had not been allowed to bring flammable materials into the football stadium and if the fire hoses had worked, the incident would not have developed into a situation that made an evacuation inevitable. The feature of smoke has had one of the strongest influences on fire response performance. Smoke blocked one escape route and obstructed the view of the emergency exit signs. The supporters' familiarity with the layout of the stadium and the difficulty of wayfinding to emergency exits were two important causes for evacuation delays. Because people knew the locations of the regular exits, they did not look for an alternate exit when the normal exit was blocked.

9.3.2 Conclusions and recommendations of the case study

Conclusion 2: The use of the FRP model results in a systematic analysis and gives a clear overview and understanding of the impact of several aspects of the occupants' fire response performance. However, the FRP model has two limitations:

- The first limitation of the FRP model is that not all features could be predicted based on existing literature. For example, the influence of escape route signage could not be predicted, neither could the influence of emergency lighting systems, building size (which appeared to have no influence in the football stadium fire), low occupant density and occupant profiles, personalities and familiarity with the layout (which appeared to have a negative influence in the football stadium fire).
- The second limitation is that the FRP model provides a qualitative analysis. This means that the weighting of the

effects of different features of fire response performance depends on the judgement of the researcher.

Recommendation 2: Further research is therefore recommended to make the model suitable for a more quantitative and objective analysis.

Conclusion 3: The FRP model generates a satisfactory prediction of the level of fire response performance.

Recommendation 3: The recommendation is to use the FRP model to determine plausible fire and occupant response scenarios based on building and occupancy characteristics.

Conclusion 4: The inadequate level of maintenance of the fire safety measures in the football stadium has lead to a low fire response performance level. In other case studies, inadequate maintenance was more often found to be an influencing factor for serious incident development.

Recommendation 4: Regarding the building characteristics, the obvious recommendation is that there should be greater emphasis on maintenance (of fire safety measures) to improve fire response performance. It is also recommended that the upwards spreading behaviour of smoke should be taken into account in the design of a football stadium.

Conclusion 5: Two situational factors, namely the focus point and the building evacuation team, contributed to the delay in evacuation time as well. The supporters received no signals that the match was suspended. Therefore, they continued to wait for the match to start.

Recommendation 5: To enhance fire response performance, it is recommended that the building management or evacuation team put more effort into communication when an accident occurs, which should preferably be accomplished via several means of communication. It would be advisable to inform supporters clearly that the situation is not normal and therefore, adjusted behaviour is requested. In other words, they need to be supported in their powers of judgement.

9.4 Methods for research on building fire safety

9.4.1 Synopsis

Several analysis tools and models have been introduced to determine the degree of a building's fire safety. The global fire safety engineering models of available safe egress time (ASET) and required safe egress time (RSET) are examples of traditional methods of life risk assessment. Evacuation (simulation) models have been playing an important function in the transition process from prescriptive fire safety codes to performance-based ones over the last three decades. With the development of simulation tools to assist in the design procedure, the application of engineering methods has become important. Therefore, it has become more and more important to obtain the correct input parameters for the engineering methods.

Various research methods can be used to collect the necessary data on, for example, human behaviour in fire. The present knowledge about human behaviour in fires is primarily extracted from experiments, such as unannounced fire drills, and from case studies, such as incident evaluations. New methods that have been used in fire safety research are the use of simulations and serious gaming. Several researchers have already made use of a serious game for research in psychology, as it allows researchers to simulate realistic situations and induce emotions in a controlled, standardised way. Even for behavioural research during fire evacuation, serious games have been used, for example by De Vries and Sun (2009) and by Smith and Trendholme (2009).

Four research methods, namely the methods of experimental research, case studies, using evacuation simulations and use of serious games, have been analysed based on eight key aspects of research. These are the level of reality of the experimental setting, the type of observation, the level of possibility of presenting people actual stressors, the level of possibility of situation control, the level of possibility of adjusting the experimental setting, the level of possibility of identical replication of tests, the level of time and cost intensity and the level of possibility of automatic data collection.

In the analysis it is found that with the use of evacuation simulation, it is not possible to collect new data on fire response performance. This is because the observations are predictions that are based on existing assumptions of a real situation. However, with the use of simulation it is possible to develop new hypotheses that can be examined in experimental research. The research method of case studies is not the best method to gain insight into fire safety psychonomics. This is because it is hardly possible to study a pre-determined issue of research. Besides, there is a high possibility that the judgements of the survivors are not necessarily a reflection of what really happened. Nevertheless, information gained from case studies is valuable to broaden our insight into human behaviour in a real fire, especially when video footage is available to analyse. In experimental research, and in research by the use of serious gaming, it is possible to adjust the test environment to study a pre-determined issue of research. Additionally, in both methods, there is a highly achievable level of situational control, identical replication of tests and automatic data collection.

9.4.2 Conclusion and recommendation of the evaluation of research methods

Conclusion 6: The method of unannounced fire drills (experimental research) and the method of the use of serious gaming are preferred to gain the needed insight in fire safety psychonomics for fire safety policy and fire safety engineering. The method of unannounced fire drills has been endorsed scientifically in research on human behaviour in fire. However, the method of the use of serious gaming has not yet been convincingly validated for research on human behaviour.

> **Recommendation 6:** To make sensible use of serious gaming in behavioural research, it is essential to scientifically verify the validity of the new research method.

9.5 Development of serious game ADMS-BART

9.5.1 Synopsis

To implement the possibilities of virtual reality for studying human behaviour in fires in experimental research, the serious game 'ADMS-BART' has been developed. This Behavioural Assessment and Research Tool (BART) is based upon a tried and tested simulation platform that is used by emergency training organisations all over the world for years now. This simulation platform is the Advanced Disaster Management Simulator of ETC Simulation with the disaster scenarios of NIFV (NIFV-ADMS). The initial development of NIFV-ADMS started in 2000. The development of NIFV-ADMS and its training program are based on the cognitive concepts of Klein (1998) and of Rasmussen and Vicente (1989), as unexpected events, unknown situations, time pressure, and life-threatening situations are important contextual factors for emergency responders. Over 15,000 people have performed one or more training sessions with NIFV-ADMS, and its use is continuing. Most of the trainees consider the training in a virtual environment to be as stressful as a real emergency response.

To make the software of ADMS suitable for behavioural research, it was extended with several functionalities, such as a tracking and registration device as well as a virtual replica of Hotel Veluwemeer. The draft version of the research tool was made in the virtual environment of VR4MAX and is called BARTtrial. This draft version was used in a user convenience test to explore the possible necessities to fine-tune the serious game ADMS-BART during its development and to gain experience with the process of training people to use the serious game. User convenience tests have also been conducted with ADMS-BART. There were three objectives for conducting the user convenience test with ADMS-BART:

- To determine the participants' perception of the simulated environment.
- To explore the user-friendliness of the research tool.
- To determine the target group for the application of the research tool, in terms of the level of gaming experience and age.

Before the tests, the participants undertook a short training in game control skills. This training had a positive influence on the game control skills, especially for the participants without gaming experience. After the training, the average level of game control skills of the participants with gaming experience was 7.3 points on a scale from 1 (low) to 10 (high) and that of the participants without gaming experience was 6.4 points.

9.5.2 Conclusions and recommendation of the user convenience tests

Conclusion 7: The user convenience of the projection on the small screen was relatively high (mean value of 8.1). Also, the rating for the projection on the laptop screen was amply sufficient (mean value of 6.6). Tests in a virtual environment with projection on a large screen were found to cause cyber sickness. The symptoms of cyber sickness were related to the symptoms of motion sickness, such as car sickness or sea sickness.

Conclusion 8: The joystick is the game control device that scored the best rating in the user convenience tests. The participants with no game control skills gave the highest user convenience rating to the joystick (mean value of 7.5). The participants with game control skills preferred the gamepad (mean value of 7.8). However, the rating for the joystick was also satisfactory (mean value of 6.8) for this group of participants. The keyboard and mouse controlling device was not suitable for older participants and for participants without game control skills.

> **Recommendation 8:** It is recommended to exclude the keyboard and mouse as the controlling device if a serious game is used to conduct behavioural research with a normal population.

Conclusion 9: The reality of the visualisation of BARTtrial is valued to be very high (mean value of 7.4). In particular, the participants with game control skills gave a high rating for the visualisation (mean value of 8.1). Consequently, no visual revision was needed for the test sessions with ADMS-BART.

Conclusion 10: ADMS-BART can simulate a realistic environment and participants do not treat the simulated situation as a 'game'. The level of realism of the environment in ADMS-BART was found to be high, varying between 7.6 and 8.0 points in the various test scenarios. Additionally, the feeling of emergency was moderate, varying between 5.8 and 6.5 points in the various test scenarios.

Conclusion 11: There is no reason to assume that the user interface (man-machine interface) of ADMS-BART would affect the behaviour in the virtual environment, as the ease of controlling the game was judged to be high (7.0-7.7), even though half of the participants had no gaming experience. There is no need to exclude older participants or participants with a low level of game control skills from evacuation tests in a virtual environment, as there is no reason to assume that the age and the level of game control skills after training has had an important influence on the exit choice for both groups of participants.

9.6 Experimental study on wayfinding during fire evacuation in a hotel

9.6.1 Synopsis

To obtain insight into human behaviour in fires, experimental research on wayfinding behaviour was conducted. The experiments were carried out in real and in virtual environments. An ethical commission of the University of Groningen approved the research design. Before the tests, the participant signed an informed consent form.

The research in the real environment was conducted with a traditional method, namely the registration and evaluation of a partially unannounced fire drill. The participants were individually alarmed by means of a telephone message. The evacuation tests were carried out in Hotel Veluwemeer, located near the Dutch city of Amersfoort. The test sessions in the real hotel consisted of an evening session and a night session, though the participants were only told about the evening session. In the evening session, a group meeting and a fake test took place. The design of the fake test was such that the participants believed that it was the actual test, so that they did not truly expect a fire drill during the night. The actual test, however, took place at night, when the participants had to evacuate individually.

Research in the virtual environment was conducted in a replica of Hotel Veluwemeer in the serious game ADMS-BART. In the virtual environment, the test session consisted of a training session and an evacuation test. The design of the evacuation test was basically the same as in the real hotel. However, in the evacuation test, the participant stood in front of a 1.0 x 1.5 meter-sized flat projection screen. After the lights were turned off, the test would start, and the participant had to act as if it was a real situation. The situation was introduced as a night situation in a hotel, and the participant would be asleep in his/her hotel room. The visualised room was the same room that was used in the training session.

The research consisted of experiments that were carried out in four settings and labelled as ‘scenarios’. In the real environment, three scenarios were tested, and, in the virtual environment, four scenarios were tested, see Figure 9.2.

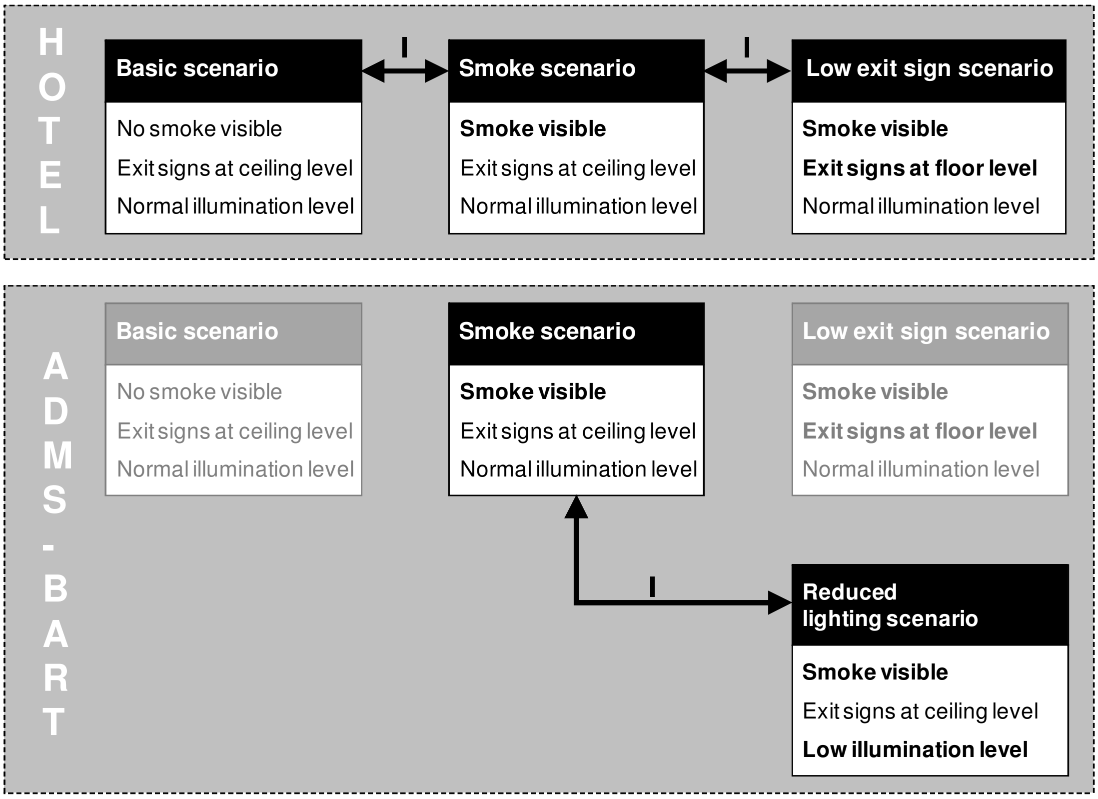


Figure 9.2. Experiment scenarios for behavioural analysis

In the first scenario, nothing was changed in the hotel setting. This was called the 'basic scenario'. In the second scenario, a fire was simulated by pouring smoke out of a hotel room into the corridor. This was called the 'smoke scenario'. In the third scenario, a fire was simulated, and the green exit signs were placed at the floor level instead of at the ceiling level. This was called the 'low exit sign scenario'. The signs in the low exit sign scenario were placed about 30 centimetres above the floor and in front of every set of two hotel room doors. Therefore, there were more signs present in this scenario compared to the other two scenarios. In the fourth scenario, a fire was simulated, and the illumination level was reduced to emergency level (approximately one lux). This was called the 'reduced lighting scenario'.

A total of 83 tests in the real environment and 46 tests in the virtual environment were used for the behavioural analysis. The main focus of the experimental research was on wayfinding during fire evacuation. The study presents the results of four possible influencing aspects on human fire response performance, namely

the influences of:
- Personal features
- Environmental conditions (smoke or no smoke)
- The location of exit signs (placed high or placed low)
- The illumination level (normal level or reduced level)

The fire response performance was measured by exit choice, walked distance and evacuation time. To analyse the influence of environmental conditions on the level of human fire performance, the results of the smoke scenario were compared to the results of the basic scenario (see 'I' in Figure 9.2). The possible influence of the location of exit signs was analysed by comparing the results of the low exit sign scenario with the results of the smoke scenario. To analyse the influence of the illumination level, the results of the reduced lighting scenario were compared with the results of the smoke scenario. The tests in all three scenarios in the real environment were analysed in detail, as the method of fire drills in a real building is a scientifically endorsed method for behavioural analysis. In the sessions with ADMS-BART, only the tests in the reduced lighting scenario and the smoke scenario were analysed in detail, since the validation of ADMS-BART was the main motive for the tests in the virtual environment and not the behavioural analysis.

9.6.2 Conclusions and recommendations of experiments in real environment

Conclusion 12: The presence of smoke has a significant influence on exit choice.
- Evacuees are more likely to evacuate via the nearest fire exit if smoke blocks the route to the main exit.
- Smoke has a negative influence on the opinion of ease of wayfinding by participants who evacuated via the main exit.

> **Recommendation 12:** Measures should be taken to persuade occupants to evacuate via the nearest fire exit, because a considerable number of the occupants (31%) evacuated towards the main exit even when the route was blocked by smoke. In a real fire situation, this behaviour may have harmed people.

Conclusion 13: There is sufficient evidence to conclude that the low location of exit signs has a positive effect on the use of the nearest fire exit.

- Evacuees who make use of exit signs are more likely to evacuate via the nearest fire exit if the exit signs are placed at a low level.
- In the scenarios wherein smoke was present the use of exit signs was significantly more effective when they were located at floor level.
- The influence of the use of high-placed exit signs is significantly stronger when no smoke is perceptible.

  Recommendation 13: Additional research on the effectiveness of low-placed exit signs in various situations is recommended, as it may be a possible measure to persuade occupants to evacuate via the nearest fire exit.

Conclusion 14: If no smoke is perceptible, people deviate by a significantly longer distance than if smoke is perceptible. Route deviation is assumed to be an indication of wayfinding confusion.

- Evacuees are likely to show turning behaviour, as about 20% of the participants did in all of the three separate scenarios.
- In a situation where no signs of a real fire are perceived (other than the fire alarm message), occupants hesitate to use a fire exit and are likely to deviate by turning to use the familiar 'normal exit'.
- The route deviation by turning in a smoky situation generally leads to evacuation via the nearest fire exit.

  Recommendation 14: More emphasis should be placed on creating a clear evacuation situation, because in a non-smoky situation, wayfinding can be confusing, and occupants hesitate to use the nearest fire exit. Additional research is needed to investigate the rationale for this hesitating behaviour and to determine possible cues that will convince occupants of the need to use the fire exit. The use of the fire exit is needed even when signs of fire, such as smoke, are not perceptible in the near surrounding, as smoke may be present in the following part of the chosen route.

Conclusion 15: Prior knowledge of the surroundings, including knowledge of the location of the nearest fire exit from prior inspection or use of an escape route map, leads to significantly more frequent use of the nearest fire exit. The prior knowledge of a person who has had BET training has no strong influence on exit choice in a fire evacuation.

> **Recommendation 15:** More emphasis should be placed on the use of escape route maps; for example, by giving information about the escape route map when guests check in for a hotel stay. Training in fire safety (for example, becoming familiar with the route to the nearest fire exit) is also an effective means of increasing the use of fire exits. Further research is needed to explore the effect of fire safety training on wayfinding behaviour.

Conclusion 16: Assumptions in Dutch legislation on walking behaviour are not consistent with the findings in the experimental research. The experimental findings on walking speed and walking distance revealed the following:

- The walking speed in the experiments (i.e., about 0.9 m/s) complied with the walking speed given in Dutch legislation (i.e., 0.83 m/s). However, 42% of the participants in the experiments walked slower than 0.83 m/s.
- A walking speed of 1 m/s is needed to walk the accepted 30 meters in 30 seconds in an assembly building, such as a nightclub, with a high occupancy density of 0.77 to 2 persons per m^2. In the experiments, 60% of participants walked slower than 1 m/s, and the hotel wing had a low occupancy density.
- A walking speed of 2 m/s is needed to walk the accepted 60 meters in 30 seconds in new shop buildings with a low occupancy density of 0.05 persons per m^2. Only 6% walked 2 m/s in the hotel wing with a low occupancy density. Moreover, this was the fastest measured walking speed.
- Regulations assume that occupants walk the shortest route in emergencies. In the scenario without perceptible smoke 70% of the participants did not evacuate via the shortest route, and in the scenarios with perceptible smoke approximately 35% did not take the shortest route. Thus, it is expected that breathing problems will arise if the shortest route to a fire door is close to the accepted 30 meters for several occupancies, or 60 meters for new shop buildings.

> **Recommendation 16**: The recommendation is to reconsider the assumptions on walking speed and walking distance in the Dutch legislation.

Conclusion 17: The suitability of questionnaires and interviews after a fire evacuation is disputable when they are used as methods for research on human behaviour in fire, given that some participants recalled instructions that had not been given, or declared to have seen smoke in the scenario without smoke.

> **Recommendation 17:** The recommendation is to interpret evacuees' responses carefully, particularly if these methods are used to evaluate real fire incidents some time after the actual event. Other recommendations include using techniques to eliminate unreliable accounts by fire survivors, using real-time observations of people's behaviour during evacuation (for example, by evaluating video recordings during a real fire evacuation), and using serious gaming.

9.6.3 Conclusions and recommendations of the experiments in the virtual environment

Conclusion 18: The illumination level had a significant influence on the exit choice.

- Evacuees were more likely to evacuate via the nearest fire exit if the illumination level was at the normal level.
- A low illumination level is assumed to increase the sense of haste, though it does not lead to a faster evacuation or to significantly more likely use of the nearest fire exit.

> **Recommendation 18:** The recommendation is to reconsider the requirements in existing regulations that currently suggest a low illumination level in case of emergencies.

Conclusion 19: Illuminated exit signs are a possible measure to persuade occupants to evacuate via the nearest fire exit in a situation with a low illumination level. The use of exit signs is namely significantly effective in the reduced lighting scenario. On the contrary, based on the significantly longer route deviation, it was found that wayfinding was confusing in the scenario with the low illumination level.

> **Recommendation 19:** The recommendation is to conduct additional research on the effectiveness of route signage designed in contrast with the environmental situation.

Conclusion 20: In the smoke scenario, participants who evacuated via the nearest exit were significantly younger than the participants who evacuated via another exit. Other assessed profile aspects, such as gender and education level, did not influence exit choice.

9.6.4 Conclusions of the comparison of findings in literature and in the experiments

Conclusion 21: The experimental findings were compared to findings in the literature. The experimental findings confirmed the following findings in literature:

- Smoke has a negative influence on wayfinding performance. Thus this negative influence of smoke should be considered in evacuation time calculations.
- People with strong social bonds will show affiliative behaviour, such as knocking on the doors of friends and relatives. Thus the influence of affiliative behaviour should be considered in evacuation time calculations.

The experimental findings suggest that the following aspects of wayfinding are not yet fully understood or addressed in the literature:

- Contrary to the findings in literature, many participants in the experiments claimed that they made use of the exit signs, although one-third of the participants in the smoke scenario did not follow instructions on the exit signs.
- The findings on movement times may indicate that the sense of emergency is higher when smoke is visible. Nevertheless, this assumption is not supported by the results of the participants' answers in the questionnaire.

Recommendation 21: Fire safety regulations and calculations should incorporate findings on fire safety psychonomics, such as the findings of a negative influence of smoke on wayfinding performance and of the effect of affiliative behaviour on fire response performance. Additionally, more research should be carried out on fire safety psychonomics, and particularly on perceptions of the situation and surroundings and on behavioural intentions and motives.

9.7 Validation of serious game ADMS-BART

9.7.1 Synopsis

The new research method that uses serious gaming has been developed to obtain insight into evacuation behaviour and the effect of the building design on that evacuation behaviour, in particular on wayfinding. Moreover, to make sensible use of the new research method, it has been validated by comparing the results of the tests in the virtual hotel in the serious game ADMS-BART with results of the same kind of tests in the real hotel. No participants tested in the real hotel experiment were also involved in the ADMS-BART experiment.

In total, 153 tests in three scenarios were successfully accomplished for the validation analysis, namely 83 tests in the real hotel and 70 tests in the virtual hotel. In every separate experiment scenario, both in the real and in the virtual hotel, at least 20 persons took part. To validate ADMS-BART, the results of the basic, smoke and low exit sign scenarios in the real hotel were compared to the results of the same scenarios in the virtual hotel. In the validation study, it is analysed to what extent the results concurred. The results consisted of a combination of certain vital actions, certain exit choice (main exit, nearest fire exit or other fire exit) and certain route choice (total length of the chosen route) per scenario. Other results that were studied included the movement time and the motivations for the participants' behaviour.

The validation study consisted of four validation steps:
- Step 1: Analysis of possible differences in test group
- Step 2: Analysis of absolute validity
- Step 3: Analysis of relative validity
- Step 4: Analysis of possible influence of the level of gaming skills on test results

To justify using ADMS-BART for future experiments, the relative validation (step 3) was considered to be more important than the absolute validation (step 2). The processes of relative and absolute validation were conducted separately for each of the three scenarios (basic scenario, smoke scenario and low exit sign scenario).

9.7.2 Conclusions and recommendation of the validation analysis

Conclusion 22: ADMS-BART is not intended as a tool for research on the movement speed during fire evacuation, as the measured movement speed in the virtual hotel is based on four fixed walking velocities (running, walking, crawling, and standing).

Conclusion 23: The use of ADMS-BART can be considered valid as a research tool for studying wayfinding behaviour during fire evacuation in a non-smoky situation and for studying the influence of smoke on wayfinding during fire evacuation.

> There is no reason to conclude that the effect of smoke is different in the virtual and real environments. There is, however, an indication that the effect of the location of the exit signs may be different in the virtual and real environments. This difference was probably due to an inconsistency in the low-exit-sign scenario, as a significant difference was found in the exit choices between the two test environments. In the virtual environment, it deviated from the assumption that if the exit signs were placed at floor level (low-exit-sign scenario) more participants would evacuate via the nearest fire exit than if the exit signs were placed at ceiling level (smoke scenario).
>
> **Recommendation 23:** To confirm the validity of ADMS-BART, it is recommended to conduct the tests with the serious game for a second time in the low exit sign scenario. When the results of the reiterated tests are analysed, special attention is recommended in the analysis of the influences of the four variables of the participants' motivations and perception that were correlated with exit choice in the real environment but not in the virtual environment, namely:
> - Consideration of the safest route
> - Presence or absence of use of exit signs
> - Prior inspection of the escape route
> - Sense of emergency

Conclusion 24: ADMS-BART can be considered suitable for participants with a high level of game control skills and for participants with a low level of game control skills.

Conclusion 25: Evidently, experimental research in the virtual setting of ADMS-BART is more convincing for participants than experimental research in a real-world setting, as some vital emotions, namely the sense of emergency, the sense of haste and the sense of stress, are significantly stronger in the tests in the virtual environment compared to the tests in the real environment. Additionally, there is no reason to assume that the behavioural levels in the virtual environment would be more optimistic than the behaviour levels in a real environment.

Samenvatting met Conclusies en Aanbevelingen

1 Introductie

Het cruciale aspect van brandveiligheid van gebouwen is de mogelijkheid voor het veilig vluchten. Een belangrijke voorwaarde hierbij is dat de brandveiligheidsvoorzieningen in het gebouw in geval van brand een zelfstandige en adequate reactie van de aanwezigen mogelijk maakt. In de praktijk blijken de huidige bij wet voorgeschreven veiligheidsmaatregelen niet altijd de ondersteuning te bieden die mensen in geval van brand nodig hebben. Dit komt doordat in de loop van de eeuwen een hiaat is ontstaan tussen enerzijds het brandveiligheidsbeleid en anderzijds de technologische en menselijke aspecten die daadwerkelijk de brandveiligheid bepalen. Bovendien worden in het huidige (Nederlandse) beleid diverse veronderstellingen gedaan die niet consistent zijn met de kennis uit de literatuur. Om de brandveiligheidsmaatregelen zo te ontwerpen dat zij de benodigde ondersteuning bieden tijdens een incident, is het inzicht in het menselijk gedrag bij brand en gedurende een evacuatie van essentieel belang. Daarom zou gebruik gemaakt moeten worden van de beschikbare wetenschappelijke kennis op het gebied van psychonomie. Psychonomie omvat een benadering van psychologie die gericht is op het ontdekken van de wetmatigheden die de werking van de menselijke geest bepalen. Deze wetmatigheden geven inzicht in de wijze waarop mensen informatie verwerken. Bij psychonomie op het gebied van brandveiligheid gaat het vooral om de menselijke perceptie van brand en de gebouwde omgeving.

De psychonomische benadering kan geïmplementeerd worden door gebruik te maken van een beoordelingssysteem dat is gebaseerd op de principes van *Fire Safety Engineering*. Met dit beoordelingssysteem kunnen de benodigde brandveiligheidsmaatregelen voor een gebouwontwerp vastgesteld worden op basis van drie scenario's, namelijk het brandscenario, het brandbestrijdingsscenario en het gedragscenario van de aanwezigen in een gebouw. Om een aannemelijk gedragsscenario te kunnen voorspellen, is nieuwe data nodig over evacuatiegedrag in verschillende omgevingen en omgevingscondities. Omdat extra psychische spanningen als gevolg van oriëntatieproblemen de cognitieve processen en het menselijk gedrag kunnen aantasten, is het gemak om de weg (naar een nooduitgang) te vinden – oftewel, het gemak van wayfinding - zeer belangrijk voor het overleven van een evacuatie bij brand. Wayfinding kan worden beschreven als het proces van ruimtelijke oriëntatie en besluitvorming, waarbij voor de navigatie in een gebouwde omgeving gebruik wordt gemaakt van ruimtelijke kennis en aanwijzingen uit die omgeving. Hoewel sommige aspecten van wayfinding tijdens evacuatie zijn onderzocht, wordt het niet uitvoerig in de literatuur besproken. In het bijzonder is er weinig inzicht in de wijze waarop inzicht mensen hun vluchtroute vinden en hoe dit proces van wayfinding met lay-out en ontwerpmaatregelen kan worden ondersteund.

Om nieuwe data over het menselijk gedrag bij brand te verzamelen kan praktijkonderzoek uitgevoerd worden. Bij praktijk-onderzoek op gebied van menselijk gedrag bij brand is het verstandig om het onderzoek uit te voeren in omgevingscondities die vergelijkbaar zijn met een echte brandsituatie. Maar om de veiligheid van de testpersonen te kunnen garanderen is het in een praktijkonderzoek nauwelijks verantwoord om mensen op een realistische wijze bloot te stellen aan het fenomeen van brand. De confrontatie met stressoren van een echte brand is aanwezig bij casestudies, maar dit type van brandonderzoek wordt bepaald door de situatie van het incident en wordt niet gestuurd door een specifieke kennisbehoefte. In een serious game is het mogelijk om mensen op een realistische wijze te confronteren met het fenomeen brand, zonder hen daarbij bloot te stellen aan de enorme gezondheidsrisico's van een echte brand. De verwachting is daarom dat de toepassing van serious games een waardevolle aanvulling is op de huidige onderzoeksmethoden. Deze nieuwe onderzoeksmethode is naar verwachting geschikt om op basis van psychonomie de benodigde brandveiligheidsvoorzieningen in een gebouwontwerp vast te kunnen stellen.

Een serious game is een spel dat gebruik maakt van interactieve simulatie door middel van computertechnologie. Interactieve simulatie is de weergave van de rol van een mens, de omgeving, of beiden, die in de loop van de speltijd zullen veranderen als de speler wel of geen acties uitvoert. Serious games hebben het doel om bij de spelers een variatie van cognitieve, sensorische en emotionele ervaringen te veroorzaken, ongeacht de middelen waaruit het spel bestaat.

Tekstbox 1.

De belangrijkste doelstelling van het onderzoek is de validatie van een nieuwe onderzoeksmethode, waarbij gebruik gemaakt wordt van serious gaming. Deze nieuwe onderzoeksmethode bestaat uit een analysemodel waarmee de zelfredzaamheid bij brand in gebouwen op systematische wijze bestudeerd kan worden (Analysemodel vluchtveiligheid), en uit een virtuele omgeving waarin het menselijk gedrag uitvoerig bestudeerd kan worden, namelijk de serious game ADMS-BART. Nadat het gebruik van ADMS-BART als onderzoeksmethode is gevalideerd, kan een veelvoud aan experimenten uitgevoerd worden om te bepalen welk gebouwontwerp het beste past bij het werkelijke menselijk gedrag bij brand.

De nieuwe onderzoeksmethode is ontwikkeld om inzicht te krijgen in evacuatiegedrag en in het effect van het gebouwontwerp op dat evacuatiegedrag, en in het bijzonder op wayfinding. De aanvullende doelstellingen van het onderzoek zijn daarom de volgende:

- Het verkrijgen van inzicht in het menselijk gedrag bij brand, in het bijzonder in de intenties waarop evacués hun vluchtroute bepalen.
- Het bestuderen van de invloed van aspecten van menselijke factoren, gebouwfactoren en brandfactoren op de zelfredzaamheid bij brand, en met name op het vermogen om de weg te kunnen vinden (wayfinding).

2 Resultaten uit de literatuurstudie

2.1 Synopsis

Het wetenschappelijk onderzoek op gebied van menselijk gedrag bij brand is relatief nieuw, hoewel sinds het begin van de 20ste eeuw meerdere studies op dit gebied zijn uitgevoerd. Toch is onze kennis over het menselijk gedrag bij brand op dit moment nog zeer beperkt. Om het brandveiligheidsbeleid te kunnen optimaliseren, is het belangrijk om te begrijpen waarom bepaalde incidenten hebben geleid tot vele slachtoffers, of waarom een schijnbaar rampzalige gebeurtenis in zeer weinig slachtoffers resulteerde. Deze vragen waren het uitgangspunt voor een literatuurstudie, die was gericht op het identificeren van de kritieke factoren die van invloed zijn op de zelfredzaamheid bij brand.

> Zelfredzaamheid bij brand is het menselijk vermogen om signalen van gevaar waar te nemen en te interpreteren, om beslissingen te nemen en om acties uit te voeren die gericht zijn op het overleven van een brandsituatie.

Tekstbox 2.

De definitie van zelfredzaamheid bij brand is gebaseerd op de kennis over het evacuatieproces. Dit proces is opgedeeld in drie activiteiten en fasen:

- Bewustwording van gevaar door externe stimuli (periode van waarneming)
- Validatie van en reactie op gevaarsignalen (periode van besluitvorming)
- Verplaatsing naar / schuilen op een veilige plaats (periode van verplaatsing)

Uit diverse incidentanalyses is een verband gevonden tussen een vertraagde ontvluchting en een groot aantal doden of gewonden, vooral in gebouwen waarin wordt geslapen, zoals woongebouwen en hotels. Om te bepalen welke maatregelen de periode van waarneming en besluitvorming kunnen verkorten, en welke aspecten van invloed zijn op de keuzes die gemaakt worden, is informatie nodig over de percepties, intenties en motieven van mensen die een brand proberen te ontvluchten. Uit de literatuurstudie naar de kritische factoren die de zelfredzaamheid bepalen, is naar voren gekomen dat het menselijk gedrag wordt bepaald door een interactie met de omgevingscondities en met de brandveiligheidsvoorzieningen in het gebouw. Op hoofdlijnen zijn drie categorieën van factoren bepalend voor de mate van zelfredzaamheid bij brand:

- Brandkenmerken
- Menskenmerken
- Gebouwkenmerken

Deze drie groepen van factoren zijn onderverdeeld in meerdere gedetailleerde kenmerken.

2.2 Conclusie en aanbeveling uit de literatuurstudie

Conclusie 1: De huidige kennis over het menselijk gedrag bij brand moet worden uitgebreid door nader onderzoek uit te voeren.

- Er is nader onderzoek nodig naar de invloed van omgevingsfactoren (brandsituatie, gebouwontwerp en sociale factoren) op het menselijk gedrag bij brand in gebouwen. In het bijzonder bestaat er nog weinig inzicht in de wijze waarop mensen hun vluchtroute vinden. Ook is er nog nauwelijks onderzoek gedaan naar hoe dit proces (van wayfinding) door de lay-out en het gebouwontwerp ondersteund kan worden.
- Voor brandveiligheidsbeleid is nadere kennis nodig over maatregelen die een positieve invloed zullen hebben op de

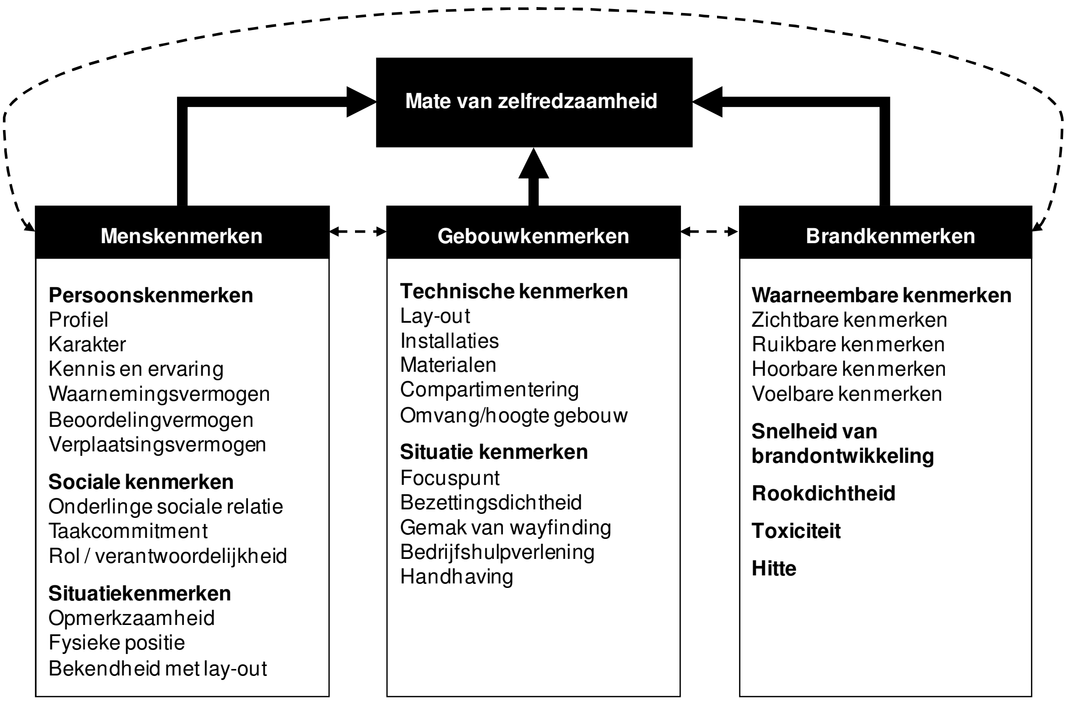
zelfredzaamheid bij brand. Om te bepalen welke maatregelen de besluitvormingstijd zullen verkorten en welke voorzieningen zullen leiden tot de keuze van de juiste vluchtroute, is informatie nodig over de perceptie, intenties en motieven van mensen die bij brand uit een gebouw vluchten.

Aanbeveling 1: Brandveiligheidsmaatregelen zouden gebaseerd moeten zijn op de psychonomische interactie tussen de gebouwkenmerken en het menselijk gedrag bij brand.

3 Case studie op basis van het 'Analysemodel vlucht-veiligheid'

3.1 Synopsis

Uit de literatuurstudie is naar voren gekomen dat de mate van zelfredzaamheid wordt beïnvloed door drie groepen van factoren, namelijk de brandkenmerken, de menskenmerken en de gebouwkenmerken.



Figuur 1. Kritische factoren voor zelfredzaamheid bij brand (Analysemodel vluchtveiligheid)

De drie groepen factoren, en de subfactoren, zijn samengebracht in het 'Analysemodel vluchtveiligheid'. Daarmee geeft het analysemodel een overzicht van de kritieke factoren die de zelfredzaamheid bij brand in gebouwen bepalen. Het model houdt rekening met de interactie tussen de menskenmerken en de gebouwkenmerken, evenals met de interactie tussen menskenmerken en brandkenmerken en met de interactie tussen brandkenmerken en gebouwkenmerken. Het analysemodel is weergegeven in figuur 1.

Om het analysemodel toepasbaar te maken voor nader onderzoek naar het menselijk gedrag bij brand in gebouwen, is het model omgevormd tot een kwalitatief analysemodel. De verwachte invloed van de typerende kenmerken van zelfredzaamheid bij brand zijn op basis van de gegevens uit de literatuurstudie bepaald. Bovendien is de toepassing van het kwalitatieve analysemodel als een *a priori theorie* voor case studies naar brandveiligheidpsychonomie geverifieerd. Voor de verificatie is het analysemodel gebruikt bij een case studie naar het menselijk gedrag bij brand in een voetbalstadion.

Uit de case studie is naar voren gekomen dat de voorspellingen in het analysemodel overeenkomen met de kenmerken die bij de brand in het voetbalstadion een rol speelden. Er moet alleen een extra invloedsniveau aan de factor 'hitte' worden toegevoegd, namelijk de positieve invloed van een gemiddeld hitteniveau; dit is slechts een kleine wijziging in het model.

Verder is uit de case studie naar voren gekomen dat de handhaving van veiligheidsvoorschriften een essentiële rol speelt bij het ontstaan van een incident. Als de toeschouwers geen brandbare materialen konden meenemen in het voetbalstadion, en als de brandslanghaspels hadden gefunctioneerd, zou het incident niet geleid hebben tot een situatie die een evacuatie onvermijdelijk maakte. De rook was één van de kenmerken die het sterkst van invloed is geweest op de zelfredzaamheid bij brand. De rook blokkeerde een van de vluchtroutes en belemmerde het zicht op de vluchtrouteaanduidingen. Twee belangrijke redenen voor de vertraagde ontvluchting waren de bekendheid van de supporters met de lay-out van het stadion, en de moeilijkheid om de weg naar de nooduitgangen te vinden. Omdat de aanwezigen de locaties van de normale uitgangen kenden, zochten zij geen alternatieve uitgang op het moment dat de gebruikelijke uitgangen geblokkeerd waren.

3.2 Conclusies en aanbevelingen uit de case studie

Conclusie 2: Het gebruik van het 'Analysemodel vluchtveiligheid' resulteert in een systematische analyse. Verder geeft het een duidelijk overzicht van, en inzicht in, het effect van verschillende aspecten van de zelfredzaamheid bij brand van de aanwezigen in een gebouw. Wel heeft het analysemodel twee beperkingen:

- De eerste beperking van het analysemodel is dat niet alle eigenschappen op basis van de bestaande literatuur voorspeld kunnen worden. Zo kon de invloed van vluchtrouteaanduiding niet worden voorspeld. Ook kon de invloed van een noodverlichtingsysteem, de omvang van het gebouw (wat geen invloed leek te hebben bij de brand in het voetbalstadion), de lage bezettingsdichtheid en de gebruikersprofielen, de invloed van de persoonlijkheid van de aanwezigen en de bekendheid met de lay-out (wat een negatieve invloed leek te hebben bij de brand in het voetbalstadion) niet worden voorspeld.
- De tweede beperking is dat het analysemodel een kwalitatieve analyse levert. Dit betekent dat de weging van de effecten van verschillende kenmerken van zelfredzaamheid afhangt van het oordeel van de onderzoeker.

Aanbeveling 2: Om het model geschikt te maken voor een meer kwantitatieve en objectieve analyse wordt aanbevolen om nader onderzoek te doen.

Conclusie 3: Het 'Analysemodel vluchtveiligheid' geeft een afdoende voorspelling van de mate van zelfredzaamheid bij brand.

Aanbeveling 3: Aanbevolen wordt het 'Analysemodel vluchtveiligheid' te gebruiken om denkbare brand- en gedragsscenario's vast te stellen die gebaseerd zijn op de gebouwkenmerken en op de kenmerken van de aanwezigen in het gebouw.

Conclusie 4: Het ontoereikende onderhoudsniveau van de veiligheidsvoorzieningen in het voetbalstadion heeft geleid tot een lage mate van zelfredzaamheid. In andere case studies is vaker gebleken dat een slecht onderhoudsniveau leidt tot een ernstig incident.

Aanbeveling 4: Met betrekking tot de gebouwkenmerken is het duidelijk dat er een grotere nadruk op het onderhoud (van brandveiligheidsvoorzieningen) zou moeten liggen, Om daarmee de zelfredzaamheid te verbeteren. Daarnaast wordt geadviseerd om bij het ontwerp van een voetbalstadion rekening te houden met de factor van opwaartse rookverspreiding.

Conclusie 5: Twee situationele factoren, namelijk het focuspunt en het BHV-team, droegen eveneens bij aan de vertraging in de evacuatietijd. De supporters kregen geen signalen dat de wedstrijd werd uitgesteld. Daarom bleven zij wachten op de start van de wedstrijd.

Aanbeveling 5: Om de zelfredzaamheid te verbeteren, wordt aanbevolen dat het gebouwmanagement of het BHV-team meer inzet op communicatie wanneer zich een ongeval voordoet. Dit zou bij voorkeur via meerdere communicatiemiddelen gedaan moeten worden. Het is raadzaam duidelijk aan de supporters mee te delen dat de situatie niet normaal is en dat daarom aangepast gedrag nodig is. Met andere woorden, zij moeten ondersteund worden in hun beoordelingsvermogen.

4 Methoden voor onderzoek naar brandveiligheid van gebouwen

4.1 Synopsis

Er zijn verschillende analyse-instrumenten en modellen ontwikkeld om het niveau van brandveiligheid van een gebouw te bepalen. De wereldwijd toegepaste *Fire Safety Engineering* modellen voor de bedreigtijd (ASET) en de vluchttijd (RSET) zijn voorbeelden van traditionele methoden voor risicobeoordeling. Evacuatie(simulatie) modellen hebben in de afgelopen drie decennia een belangrijke rol gespeeld in het overgangsproces van prescriptieve regelgeving op gebied van brandveiligheid naar *performance based* regelgeving. Met de ontwikkeling van simulatietools voor de ondersteuning in het ontwerpproces is de toepassing van *engineering* methoden belangrijk geworden. Daarom is het nog belangrijker om de juiste inputparameters voor *engineering* methoden te verkrijgen.

Om de noodzakelijke gegevens te verzamelen, bijvoorbeeld over menselijk gedrag bij brand, kunnen verschillende onderzoeksmethoden worden toegepast. De huidige kennis over menselijk gedrag bij brand wordt voornamelijk gehaald uit experimenten, zoals onaangekondigde ontruimingsoefeningen, en uit case studies, zoals incidentevaluaties. Nieuwe methoden die in brandveiligheidsonderzoek toegepast worden zijn het gebruik van simulaties en serious gaming. Meerdere onderzoekers hebben al gebruik gemaakt van een serious game in psychologisch onderzoek, aangezien het onderzoekers de mogelijkheid biedt om een realistische situatie te simuleren en emoties op een gecontroleerde en gestandaardiseerde wijze op te wekken. Zelfs voor gedragsonderzoek tijdens evacuatie bij brand zijn al serious games gebruikt, zoals door De Vries en Sun (2009) en door Smith en Trendholme (2009).

Vier onderzoeksmethoden, namelijk de methoden van praktijkonderzoek, case studies, het gebruik van evacuatiesimulaties en het gebruik van serious games, zijn geanalyseerd op acht belangrijke aspecten van onderzoek. Dit zijn het realiteitsgehalte van de onderzoeksomgeving, de type observaties, de mate waarin het mogelijk is om mensen echte stressoren te tonen, de mate waarin de situatie onder controle gehouden kan worden, de mate waarin identieke herhalingen van testen uitgevoerd kunnen worden, de tijd- en kostenintensiteit en de mate waarin automatische dataverzameling mogelijk is.

Uit de analyse blijkt dat het met evacuatiesimulaties (rekenmodellen) niet mogelijk is om nieuwe data over het menselijk gedrag te verzamelen. Dit komt doordat de simulatieresultaten voorspellingen zijn, die gebaseerd zijn op bestaande aannames over de werkelijke situatie. Wel is het met simulatie mogelijk om nieuwe hypothesen te ontwikkelen, die vervolgens met behulp van praktijkonderzoek getoetst kunnen worden. Een case studie is niet de beste methode om inzicht te verkrijgen in brandveiligheidpsychonomie, omdat het nauwelijks mogelijk is om vooraf vastgestelde onderwerpen te onderzoeken. Bovendien bestaat er bij case studies een grote kans dat de beoordelingen van de overlevenden niet noodzakelijkerwijs een reflectie zijn van wat er werkelijk is gebeurd. Toch is de informatie uit case studies wel waardevol om meer inzicht te krijgen in het menselijk gedrag bij een werkelijke brand, vooral wanneer videomateriaal beschikbaar is voor de analyse. In praktijkonderzoek, en bij het gebruik van serious gaming, kan de testomgeving aangepast worden waardoor het mogelijk is om vooraf vastgestelde onderwerpen te onderzoeken. Bovendien is er in beide methoden sprake van een hoge mate van controle over de (test)situatie, is het mogelijk om testen op identieke wijze te herhalen en om data automatisch vast te leggen.

4.2 Conclusie en aanbeveling uit de evaluatie van onderzoeksmethoden

Conclusie 6: Om voor brandveiligheidsbeleid en *fire safety engineering* het benodigde inzicht in brandveiligheidpsychonomie te verkrijgen heeft de methode van onaangekondigde ontruimingsoefeningen (praktijkonderzoek) de voorkeur, evenals de methode waarbij gebruik gemaakt wordt van serious gaming. De methode van onaangekondigde ontruimingsoefeningen is een wetenschappelijk geaccepteerde methode voor onderzoek naar menselijk gedrag bij brand. Het gebruik van serious gaming is daarentegen nog niet op overtuigende wijze gevalideerd voor onderzoek naar menselijk gedrag bij brand.

> **Aanbeveling 6:** Om op betrouwbare wijze gebruik te maken van serious gaming in gedragsonderzoek is het noodzakelijk om de validiteit van de nieuwe onderzoeksmethode wetenschappelijk te verifiëren.

5 Ontwikkeling van de serious game ADMS-BART

5.1 Synopsis

De serious game ‘ADMS-BART’ is ontwikkeld om de mogelijkheden van virtual reality voor het bestuderen van het menselijk gedrag bij brand te implementeren in praktijkonderzoek. Deze *Behavioural Assessment and Research Tool*[1] (BART) is gebaseerd op een uitgebreid toegepast en getest simulatieplatform dat al vele jaren wereldwijd wordt gebruikt bij hulpverleningstrainingen. Het simulatieplatform is de *Advanced Disaster Management Simulator*[2] van ETC Simulation met de incidentscenario’s van NIFV (NIFV-ADMS). De eerste ontwikkeling van NIFV-ADMS begon in 2000. Aangezien onverwachte gebeurtenissen, onbekende situaties, tijdsdruk en levensbedreigende situaties belangrijke contextuele

[1] Letterlijke vertaling: Gedrag beoordelings- en onderzoeksinstrument.
[2] Letterlijke vertaling: Geavanceerde rampenmanagement simulator.

factoren vormen voor hulpverleners, is het ontwerp van NIFV-ADMS en het bijbehorende trainingsprogramma gebaseerd op cognitieve concepten van Klein (1998) en van Rasmussen en Vicente (1989). Meer dan 15,000 mensen hebben een of meerdere trainingen met NIFV-ADMS gevolgd en meer trainingen zullen volgen. De meeste deelnemers aan de trainingen beoordelen de virtuele omgeving net zo stressvol als een echte hulpverleningsactie.

Om de software van ADMS geschikt te maken voor experimenteel onderzoek is het uitgebreid met meerdere functionaliteiten, zoals een volg- en registratie-instrument en een virtuele replica van Hotel Veluwemeer. Het conceptontwerp van het onderzoeks-instrument, *BARTtrial*, is gemaakt in de virtuele omgeving van VR4MAX. Dit conceptontwerp is gebruikt in een gebruiks-vriendelijkheidtest, om tijdens het ontwikkelingsproces de mogelijk noodzakelijke aanpassingen van de serious game ADMS-BART te verkennen en om ervaring op te doen met het proces om mensen te trainen in het gebruik van de serious game. Er zijn ook gebruiksvriendelijkheidtesten met ADMS-BART uitgevoerd. De gebruiksvriendelijkheidtesten met ADMS-BART hadden drie doelstellingen:

- Het vaststellen van de perceptie van de virtuele testomgeving voor deelnemers.
- Het verkennen van het gebruiksgemak van de onderzoeks-instrument.
- Het bepalen van de doelgroep voor de toepassing van de onderzoeksinstrument, in termen van het ervaringsniveau in het spelen van computerspellen en leeftijd.

Voorafgaand aan de testen kregen de deelnemers een korte training in het besturen van het computerspel. Deze training had een positieve invloed op de vaardigheid in de besturing van het computerspel, met name bij mensen zonder enkele ervaring in het spelen van een computerspel. Na de training was het gemiddelde vaardigheidsniveau van de deelnemers met ervaring 7.3 punten op een schaal van 1 (laag) tot 10 (hoog) en voor deelnemers zonder ervaring was de score 6.4 punten.

5.2 Conclusies en aanbeveling uit gebruiksvriendelijkheidtesten

Conclusie 7: De gebruiksvriendelijkheid van de projectie op een klein projectiescherm was relatief hoog (gemiddelde waarde van 8.1). Ook de waardering van de projectie op een laptopscherm was ruim voldoende (gemiddelde waarde van 6.6.). Uit de testen met een projectie op een groot projectiescherm kwam naar voren dat het simulatorziekte (cyber sickness) kan veroorzaken. De symptomen van simulatorziekte houden verband met de symptomen van bewegingsziekte, zoals wagenziekte en zeeziekte.

Conclusie 8: De joystick is het besturingsapparaat dat het hoogst scoorde in de gebruiksvriendelijkheidtest. De deelnemers zonder vaardigheid in de besturing van computerspellen gaven de hoogste waardering voor gebruiksvriendelijkheid van de joystick (gemiddelde waarde van 7.5). De deelnemers met computerspelvaardigheid gaven de voorkeur aan de gamepad (gemiddelde waarde van 7.8). Deze groep deelnemers gaf overigens ook een ruime voldoende voor de joystick (gemiddelde waarde van 6.8). De besturing met toetsenbord en muis bleek niet geschikt voor oudere deelnemers en deelnemers zonder computerspelervaring.

> **Aanbeveling 8:** De aanbeveling is om geen gebruik te maken van de besturing met toetsenbord en muis, als een serious game wordt toegepast in gedragsonderzoek met een normale populatie.

Conclusie 9: Het realiteitsgehalte van de visualisatie van *BARTtrial* is volgens de beoordelingen zeer hoog (gemiddelde waarde van 7.4). Met name de deelnemers met computerspelvaardigheid gaven een hoge score voor de visualisatie (gemiddelde waarde van 8.1). Daarom waren er geen visuele aanpassingen nodig voor de testsessies met ADMS-BART.

Conclusie 10: ADMS-BART is in staat een realistische omgeving te simuleren en deelnemers beoordeelden de gesimuleerde omgeving niet als een 'spel'. Het realiteitsgehalte van de omgeving in ADMS-BART was hoog, variërend tussen 7.6 en 8.0 punten in de verschillende testscenario's. Verder was het gevoel van een noodsituatie gemiddeld, variërend tussen 5.8 en 6.5 punten in de verschillende testscenario's.

Conclusie 11: Er is geen reden om aan te nemen dat de *user interface* (mens-machine interactie) van ADMS-BART invloed zal hebben op het gedrag in de virtuele omgeving, aangezien de beoordeling van het bedieningsgemak van het computerspel hoog is (7.0-7.7), terwijl zelfs de helft van de deelnemers geen ervaring had met het spelen van computerspellen. Het is niet nodig om oudere deelnemers of deelnemers met een laag spelvaardigheidsniveau uit te sluiten van testen in een virtuele omgeving. Er is namelijk geen reden om aan te nemen dat leeftijd en het spelvaardigheidniveau na training een belangrijke invloed heeft gehad op de uitgangskeuze van beide groepen van deelnemers.

6 Praktijkonderzoek naar wayfinding tijdens brand-evacuatie in een hotel

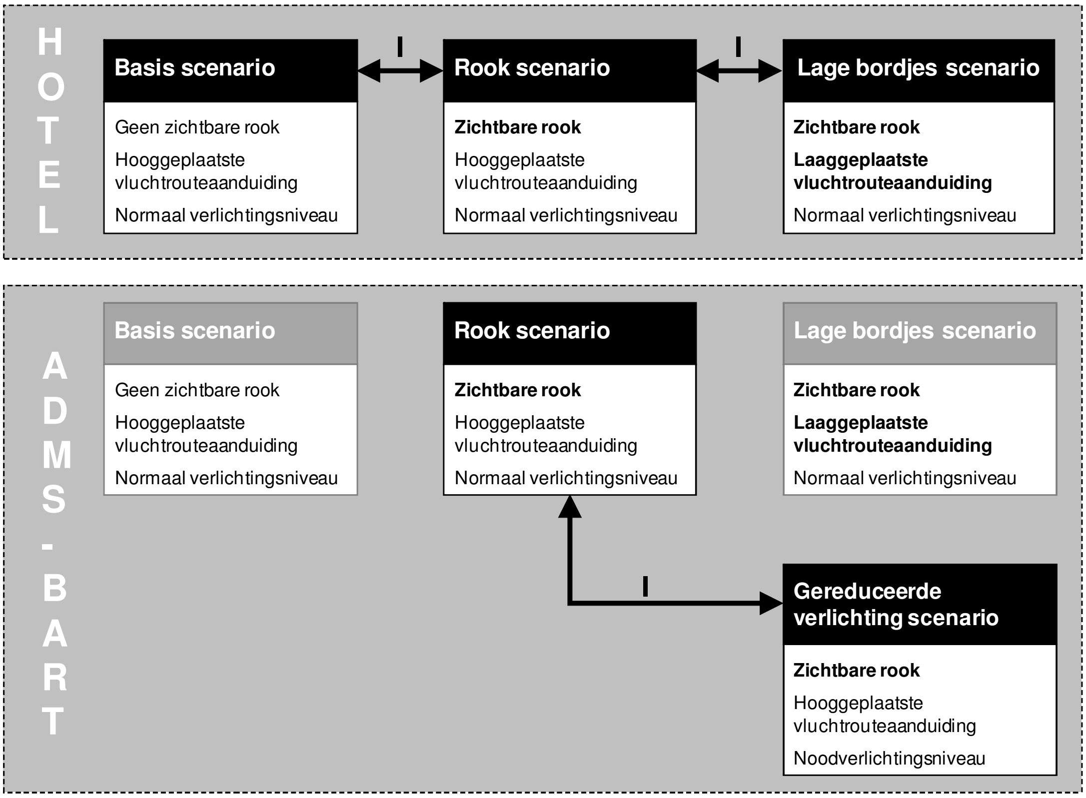
6.1 Synopsis

Om inzicht te krijgen in menselijk gedrag bij brand is praktijkonderzoek uitgevoerd naar gedrag bij wayfinding. De experimenten zijn uitgevoerd in een echte en in een virtuele omgeving. Een ethische commissie van Universiteit Groningen heeft het onderzoeksvoorstel goedgekeurd. Voorafgaand aan de testen hebben de deelnemers een toestemmingsverklaring ondertekend.

Het onderzoek in de echte omgeving is uitgevoerd met een traditionele methode, namelijk met de registratie en evaluatie van een deels onaangekondigde ontruimingsoefening. De deelnemers werden individueel gealarmeerd door middel van een telefoonbericht. De evacuatietesten zijn uitgevoerd in Hotel Veluwemeer, dat vlakbij Amersfoort ligt. De testsessies in het echte hotel bestonden uit een avondsessie en een nachtsessie, maar de deelnemers zijn alleen geïnformeerd over de avondsessie. In de avondsessie vond een groepsbijeenkomst en een neptest plaats. Het ontwerp van de neptest was zo dat de deelnemers dachten dat het de daadwerkelijke test was, waardoor ze niet echt het vermoeden hadden dat ’s nachts een ontruimingsoefening gehouden zou worden. Maar de werkelijke test vond ’s nachts plaats, waarbij de deelnemers individueel moesten evacueren.

Het onderzoek in de virtuele omgeving vond plaats in een replica van Hotel Veluwemeer in de serious game ADMS-BART. De experimenten in de virtuele omgeving bestonden uit een trainings-sessie en een evacuatietest. De opzet van de evacuatietest was in basis gelijk aan de opzet van de test in de werkelijke omgeving, met het verschil dat de deelnemer voor een projectiescherm van 1.0 x 1.5 meter stond. Nadat de lichten waren gedoofd zou de test starten en moest de deelnemer reageren alsof het een echte situatie was. De situatie werd aangekondigd als een nachtsituatie in een hotel waarbij de deelnemer in de hotelkamer zou liggen te slapen. De gevisualiseerde kamer was dezelfde kamer die in de trainingssessie was gebruikt.

Het onderzoek bestond uit experimenten die uitgevoerd werden in vier situaties, die als 'scenario' werden aangemerkt. In de echte omgeving werden drie scenario's getest en in de virtuele omgeving vonden testen in vier scenario's plaats, zie figuur 2.



Figuur 2. Testscenario's voor gedragsanalyse

In het eerste scenario was niets veranderd aan de hotelomgeving. Dit was het 'basis scenario'. In het tweede scenario werd een brand gesimuleerd door vanuit een hotelkamer rook in de gang te blazen. Dit was het 'rook scenario'. In het derde scenario was een brand gesimuleerd en waren de groene vluchtrouteaanduidingen van plafondniveau naar vloerniveau verplaatst. Dit is het 'lage bordjes scenario'. De vluchtrouteaanduidingen werden in het lage bordjes scenario op ongeveer 30 centimeter boven de vloer en voor elke set van twee hotelkamerdeuren geplaatst. In het vierde scenario werd een brand gesimuleerd en was het verlichtingsniveau gereduceerd tot het niveau van noodverlichting (ongeveer een lux). Dit was het 'gereduceerde verlichting scenario'.

In totaal zijn 83 testen in de echte omgeving en 46 testen in de virtuele omgeving gebruikt voor de gedragsanalyse. De belangrijkste focus van het experimentele onderzoek ligt op wayfinding bij ontvluchting in geval van brand. In de experimenten zijn vier aspecten voor zelfredzaamheid bij brand onderzocht die de uitkomst mogelijk beïnvloeden, namelijk de invloeden van:

- Persoonlijke factoren
- Omgevingscondities (rook of geen rook)
- De locatie van vluchtrouteaanduidingen (hoog of laag geplaatst)
- Het verlichtingsniveau (normaal of gereduceerd niveau)

De zelfredzaamheid bij brand werd gemeten aan de hand van de uitgangskeuze, de gelopen afstand en de evacuatietijd. Om de invloed van de omgevingscondities op de mate van zelfredzaamheid bij brand te analyseren, zijn de resultaten uit de testen in het rook scenario vergeleken met de resultaten uit het basis scenario (zie 'I' in figuur 2). De mogelijke invloed van de locatie van de vluchtrouteaanduidingen is geanalyseerd door de resultaten van het 'lage bordjes scenario' te vergelijken met de resultaten van het 'rook scenario'. Om de invloed van het verlichtingsniveau te analyseren zijn de resultaten van het 'gereduceerde verlichting scenario' vergeleken met de resultaten van het 'rook scenario'. De testen in alle drie scenario's in de echte omgeving zijn op detailniveau geanalyseerd, aangezien de methode van ontruimingsoefeningen in een echt gebouw een wetenschappelijk geaccepteerde methode voor gedragsonderzoek is. Aangezien de validatie van ADMS-BART het hoofdmotief was voor de testen in de virtuele omgeving, en niet de gedragsanalyse, zijn van de sessies met ADMS-BART alleen de testen in het 'gereduceerde verlichting scenario' en het 'rook scenario' nader geanalyseerd.

6.2 Conclusies en aanbevelingen uit de experimenten in de echte omgeving

Conclusie 12: De aanwezigheid van rook had een significante invloed op de uitgangskeuze.

- Evacués zullen eerder via de dichtstbijzijnde nooduitgang vluchten wanneer de route naar de hoofduitgang door rook is geblokkeerd.

- Rook had een negatief effect op de waardering van het gemak van wayfinding door de deelnemers die via de hoofduitgang zijn gevlucht.

  Aanbeveling 12: Er zouden maatregelen getroffen moeten worden om gebouwgebruikers ertoe over te halen om via de dichtstbijzijnde nooduitgang te vluchten. Een aanzienlijk deel van de deelnemers (31%) is namelijk via de hoofduitgang gevlucht, terwijl de route naar de hoofduitgang door rook was geblokkeerd. In een echte brandsituatie zou dit gedrag waarschijnlijk tot slachtoffers geleid hebben.

Conclusie 13: Er is voldoende bewijs om te concluderen dat de lage positie van de vluchtrouteaanduidingen een positief effect heeft gehad op het gebruik van de dichtstbijzijnde nooduitgang.

- Evacués die gebruik maken van vluchtrouteaanduidingen zullen eerder via de dichtstbijzijnde nooduitgang vluchten wanneer de vluchtrouteaanduiding op een lage locatie is geplaatst.
- In de situatie waarin rook aanwezig was bleek het gebruik van vluchtrouteaanduidingen significant effectiever als deze op vloerniveau waren geplaatst.
- De invloed van het gebruik van <u>hoog</u>geplaatste vluchtrouteaanduidingen bleek significant sterker wanneer geen rook zichtbaar was.

  Aanbeveling 13: Aanbevolen wordt om aanvullend onderzoek te doen naar de effectiviteit van laaggeplaatste vluchtrouteaanduidingen in verschillende situaties, omdat gebleken is dat het een mogelijke maatregel is om gebouwgebruikers ertoe over te halen via de dichtstbijzijnde nooduitgang te vluchten.

Conclusie 14: Wanneer geen rook waarneembaar is zullen mensen met een significant langere afstand van de kortste route afwijken dan wanneer rook wel waarneembaar is. Het afwijken van de kortste route wordt opgevat als een indicatie van een verwarrende wayfinding-situatie.

- De verwachting is dat evacués tijdens de ontvluchting van vluchtrichting zullen veranderen door zich om te draaien; dit deed namelijk zo'n 20% van de deelnemers in elk van de drie afzonderlijke scenario's.
- In een situatie waarin geen signalen van een echte brand waarneembaar waren (anders dan het bericht van het

brandalarm), aarzelen gebouwgebruikers om via de nooduitgang te vluchten en zullen ze zich naar verwachting omdraaien om via de 'normale uitgang', waarmee ze bekend zijn, te vluchten.

- De afwijking van de kortste route door van looprichting te veranderen (om te draaien) leidt in een situatie met rook doorgaans tot een evacuatie via de dichtstbijzijnde nooduitgang.

Aanbeveling 14: Er is meer aandacht nodig voor het creëren van een duidelijke evacuatiesituatie, aangezien de wayfinding-situatie in een niet-rokerige situatie verwarrend kan zijn en gebouwgebruikers aarzelen om via de dichtstbijzijnde nooduitgang te vluchten. Er is nader onderzoek nodig om de onderliggende redenen voor dit aarzelende gedrag te analyseren en om de mogelijke aanwijzingen vast te stellen die aanwezigen overtuigen van de noodzaak om via de nooduitgang te vluchten. Het gebruik van de dichtstbijzijnde nooduitgang is ook nodig wanneer signalen van brand, zoals rook, niet in de directe omgeving zijn waar te nemen, aangezien de rook mogelijk wel in het volgende gedeelte van de gekozen route aanwezig is.

Conclusie 15: Eerder opgedane kennis van de omgeving, namelijk de kennis van de locatie van de dichtstbijzijnde nooduitgang via een eerdere inspectie of via het gebruik van een vluchtplattegrond, leidt tot een significant frequenter gebruik van de dichtstbijzijnde nooduitgang. De eerdere kennis van een persoon die een BHV-training heeft gehad, heeft waarschijnlijk geen sterke invloed op de keuze van de uitgang bij een brandevacuatie.

Aanbeveling 15: Er is meer aandacht nodig voor het gebruik van vluchtrouteplattegronden, bijvoorbeeld door informatie te geven over de vluchtroute wanneer gasten inchecken voor een hotelovernachting. Ook is training in brandveiligheid, bijvoorbeeld door mensen bekend te maken met de route naar de dichtstbijzijnde nooduitgang, naar verwachting een effectieve maatregel om het gebruik van nooduitgangen te verbeteren. Er is nader onderzoek nodig om het effect van training in brandveiligheid op het gedrag van wayfinding te verkennen.

Conclusie 16: De aannames over het loopgedrag die in de Nederlandse regelgeving worden gedaan, komen niet overeen met de resultaten uit het praktijkonderzoek. De bevindingen uit het praktijkonderzoek over de loopsnelheid en loopafstand zijn hierna genoemd:

- De gemiddelde loopsnelheid in de experimenten, namelijk ongeveer 0.9 m/s, kwam overeen met de loopsnelheid die in de Nederlandse regelgeving is opgenomen, namelijk 0.83 m/s. Daarentegen liep 42% van de deelnemers in de experimenten langzamer dan 0.83 m/s.
- Er is een loopsnelheid van 1 m/s nodig om de geaccepteerde 30 meter in 30 seconden af te leggen in een bijeenkomstgebouw, zoals een discotheek, met een hoge bezettingsdichtheid van 0.77 tot 2 personen per m^2. In totaal liep 60% langzamer dan 1 m/s, terwijl in de hotelvleugel sprake was van een lage bezettingsdichtheid.
- Er is een loopsnelheid van 2 m/s nodig om de geaccepteerde 60 meter in 30 seconden af te leggen in een nieuw winkelgebouw met een lage bezettingsdichtheid van 0.05 personen per m^2. Slechts 6% liep met een snelheid van 2 m/s in de hotelvleugel met een lage bezettings-dichtheid. Bovendien was dit de snelste loopsnelheid die gemeten was.
- In de regelgeving wordt aangenomen dat gebouwgebruikers in geval van nood via de kortste route vluchten. In het scenario zonder waarneembare rook vluchtte 70% van de deelnemers <u>niet</u> via de kortste route, en in de scenario's met waarneembare rook vluchtte ongeveer 35% niet via de kortste route. Dat betekent dat verwacht kan worden dat ademhalingsproblemen zullen optreden wanneer de kortste route naar een 'vluchtdeur' ongeveer 30 meter is, zoals voor verschillende gebruiksfunctie geaccepteerd is in de regelgeving, of zelfs 60 meter is voor nieuwe winkelgebouwen.

Aanbeveling 16: Aanbevolen wordt om de aannames in de Nederlandse regelgeving over loopsnelheid en loopafstand opnieuw in overweging te nemen.

Conclusie 17: Gezien het feit dat sommige deelnemers zich instructies herinnerden die niet waren gegeven, of aangaven dat ze rook hadden gezien in het scenario zonder rook, valt de geschiktheid van vragenlijsten en interviews na een brandevacuatie te betwisten indien het gebruikt wordt als een methode voor onderzoek naar het menselijk gedrag bij brand.

Aanbeveling 17: Aanbevolen wordt om de antwoorden van evacués zeer voorzichtig te interpreteren. Dit geldt met name wanneer de methode gebruikt wordt om echte brandincidenten te evalueren, wat doorgaans enige tijd na het feitelijke incident plaats vindt. Andere aanbevelingen zijn om technieken te gebruiken die onbetrouwbare uitspraken van overlevenden kunnen elimineren, of om gebruik te maken van *real-time* observaties van het menselijk gedrag bij brand, bijvoorbeeld via de evaluatie van video-opnames van een echte brandevacuatie, of via het gebruik van serious gaming.

6.3 Conclusies en aanbevelingen uit de experimenten in de virtuele omgeving

Conclusie 18: Het verlichtingsniveau heeft een significante invloed gehad op de keuze van de uitgang.

- Evacués zullen eerder via de dichtstbijzijnde nooduitgang vluchten wanneer sprake is van een normaal verlichtings-niveau.
- Een laag verlichtingsniveau (ongeveer 1 lux) lijkt het gevoel van haast te versterken, maar het leidt niet tot een snellere evacuatie of tot een significant vaker gebruik van de dichtstbijzijnde nooduitgang.

Aanbeveling 18: Aanbevolen wordt om de eisen in de huidige regelgeving opnieuw in overweging te nemen, aangezien momenteel een laag verlichtingsniveau in geval van nood geaccepteerd wordt.

Conclusie 19: In een situatie met een gereduceerd verlichtings-niveau is het gebruik van verlichte vluchtrouteaanduidingen een mogelijke maatregel om gebouwgebruikers ertoe over te halen via de dichtstbijzijnde nooduitgang te vluchten. De invloed van het gebruik van de vluchtrouteaanduidingen was namelijk significant effectief in het gereduceerde verlichting scenario. Daar staat tegenover dat de wayfinding-situatie in het scenario met het gereduceerde verlichtingsniveau verwarrend bleek te zijn, gezien de significant langere afwijking van de kortste route.

Aanbeveling 19: Aanbevolen wordt om aanvullend onderzoek te doen naar de effectiviteit van een routeaanduiding die zodanig is ontworpen dat deze contrasteert met de omgevingssituatie.

Conclusie 20: In het 'rook scenario' waren de deelnemers die via de dichtstbijzijnde uitgang vluchtten significant jonger dan de deelnemers die via een andere uitgang vluchtten. Andere onderzochte aspecten van het profiel van de deelnemers, zoals geslacht en opleidingsniveau, hadden geen invloed op de uitgangkeuze.

6.4 Conclusies uit de vergelijking van bevindingen in literatuur en in experimenten

Conclusie 21: De bevindingen uit de experimenten zijn vergeleken met de bevindingen in de literatuur. De bevindingen uit de experimenten komen op de volgende punten overeen met de bevindingen in de literatuur:

- Rook heeft een negatief effect op het gemak van wayfinding. Dit betekent dat het negatieve effect van rook op het gemak van wayfinding meegewogen zou moeten worden in de berekening van de evacuatietijd.
- Mensen met een sterke onderlinge sociale band zullen 'onderling sociaal gedrag' (*'affiliative behaviour'*) uiten, zoals het kloppen op de deuren van vrienden en familie. Dit betekent dat het effect van uitingen van onderling sociaal gedrag meegewogen zou moeten worden in de berekening van de evacuatietijd.

De bevindingen uit de experimenten doen vermoeden dat de volgende aspecten van wayfinding nog niet goed zijn begrepen of geadresseerd in de literatuur:

- In tegenstelling tot de bevindingen in de literatuur verklaarden veel deelnemers in de experimenten dat zij gebruik gemaakt hebben van de vluchtrouteaanduidingen. Daarentegen volgde een derde van deze deelnemers in het 'rook scenario' niet de instructies die de vluchtroute-aanduidingen gaven.
- De bevindingen over verplaatsingstijden lijken aan te tonen dat het gevoel van een noodsituatie hoger is wanneer rook zichtbaar is. Deze veronderstelling wordt daarentegen niet bevestigd door de antwoorden van de deelnemers op de vraag over het gevoel van een noodsituatie.

Aanbeveling 21: In brandveiligheidsbeleid en berekeningen zouden bevindingen op gebied van brandveiligheidpsychnomie opgenomen moeten worden, zoals de uitkomsten van een negatieve invloed van rook op het gemak van wayfinding en van het effect van sociaal onderling gedrag op het zelfredzame gedrag bij brand. Daarnaast is er is meer onderzoek nodig op gebied van brandveiligheidpsychnomie, en in het bijzonder naar de percepties van de situatie en omgeving en naar de intenties en motieven voor gedrag.

7 Validatie van de serious game ADMS-BART

7.1 Synopsis

De nieuwe onderzoeksmethode waarin gebruik gemaakt wordt van serious gaming is ontwikkeld om inzicht te verkrijgen in evacuatiegedrag en in het effect van het gebouwontwerp op dat evacuatiegedrag, en in het bijzonder op wayfinding. Om op betrouwbare wijze gebruik te maken van de nieuwe onderzoeksmethode is het gevalideerd door de resultaten uit de testen in het virtuele hotel in de serious game ADMS-BART te vergelijken met dezelfde type testen in het echte hotel. Geen van de deelnemers die aan de testen in het echte hotel hebben meegedaan waren betrokken bij het ADMS-BART experiment.

In totaal waren 153 testen in drie scenario's succesvol voor de validatie analyse, namelijk 83 testen in het echte hotel en 70 testen in het virtuele hotel. In elk afzonderlijke testscenario, zowel in het echte als in het virtuele hotel, deden ten minste 20 personen mee. Om ADMS-BART te valideren zijn de resultaten uit de basis, rook en gereduceerd verlichting scenario's in het echte hotel vergeleken met de resultaten uit dezelfde scenario's in het virtuele hotel. In de validatie studie is geanalyseerd in welke mate de resultaten met elkaar overeenkwamen. De resultaten bestonden uit een combinatie van bepaalde belangrijke acties, een bepaalde uitgangkeuze (hoofduitgang, dichtstbijzijnde nooduitgang of een andere uitgang) en een bepaalde routekeuze (totale lengte van de gekozen route) per scenario. Andere resultaten die onderzocht zijn betreffen onder andere de verplaatsingstijd en de motivaties voor het gedrag van de deelnemers.

De validatie studie bestond uit vier validatie stappen:
- Stap 1: Analyse van mogelijke verschillen in de testgroep
- Stap 2: Analyse van de absolute validiteit
- Stap 3: Analyse van de relatieve validiteit
- Stap 4: Analyse van de mogelijke invloed van het niveau van spelvaardigheid op de testresultaten

Om het gebruik van ADMS-BART voor toekomstige experimenten te rechtvaardigen, wordt de relatieve validatie (stap 3) belangrijker geacht dan de absolute validatie (stap 2). De processen van relatieve en absolute validatie zijn voor elk van de drie scenario's (basis scenario, rook scenario, lage bordjes scenario) afzonderlijk uitgevoerd.

7.2 Conclusies en aanbeveling uit de validatie analyse

Conclusie 22: ADMS-BART is niet bedoeld als instrument voor onderzoek naar de loopsnelheid tijdens een brandevacuatie, aangezien de gemeten loopsnelheid in de virtuele omgeving gebaseerd is op vier vaste loopsnelheden (rennen, lopen, kruipen en staan).

Conclusie 23: De toepassing van ADMS-BART als onderzoeksinstrument voor kan als valide worden beschouwd voor onderzoek naar het wayfinding-gedrag in een situatie zonder rook en voor onderzoek naar de invloed van rook op wayfinding in geval van een brandevacuatie.

> Er is geen reden om aan te nemen dat het effect van rook verschilt in de virtuele en echte omgeving. Wel is er een aanwijzing dat het effect van vluchtrouteaanduidingen verschillend is in de virtuele en echte omgeving. Dit verschil is waarschijnlijk veroorzaakt door een inconsistentie in het 'lage bordjes scenario', aangezien een verschil is gevonden in uitgangskeuzes tussen de twee testomgevingen. In de virtuele omgeving wijkt het af van de aanname dat als de vluchtrouteaanduidingen op vloerniveau zijn geplaatst (lage bordjes scenario) meer deelnemers via de dichtstbijzijnde nooduitgang zullen vluchten dan wanneer de vluchtrouteaanduidingen op plafondniveau zijn geplaatst (rook scenario).

Aanbeveling 23: Om de validiteit van ADMS-BART te aan te tonen wordt aanbevolen om de testen met de serious game in het 'lage bordjes scenario' opnieuw uit te voeren. Wanneer de resultaten van deze opnieuw uitgevoerde testen worden geanalyseerd is het de aanbeveling om speciale aandacht te schenken aan de analyse van de invloeden van de vier variabelen in motivaties en perceptie van deelnemers, die een corelatie hadden met de uitgangkeuze in de echte omgeving, maar niet in de virtuele omgeving, te weten:

- Overweging van de veiligste route
- Wel of geen gebruik van vluchtrouteaanduidingen
- Eerdere inspectie van de vluchtroute
- Gevoel van een noodsituatie

Conclusie 24: ADMS-BART kan als geschikt worden beschouwd voor deelnemers met een hoog spelvaardigheidniveau, alsook voor deelnemers met een laag spelvaardigheidniveau.

Conclusie 25: Het is evident dat praktijkonderzoek in de virtuele omgeving van ADMS-BART voor deelnemers overtuigender is dan het praktijkonderzoek in een echte omgeving, aangezien enkele belangrijke emoties, namelijk het gevoel van nood, het gevoel van haast en het gevoel van stress, significant sterker zijn in de testen in de virtuele omgeving in vergelijking met de testen in de echte omgeving. Bovendien is er geen reden om aan te nemen dat de gedragingen in de virtuele omgeving optimistischer zouden zijn dan de gedragingen in de echte omgeving.

Dankwoord

Dit proefschrift is het resultaat van een onderzoek dat gedurende meerdere jaren is uitgevoerd. In die periode heb ik met een groot aantal mensen samengewerkt. Zij hebben op verschillende manieren een bijdrage geleverd aan het onderzoek en verdienen daarvoor speciale aandacht. Het is doet me plezier om in dit dankwoord mijn waardering uit te spreken aan allen die een belangrijke invloed hebben gehad op de succesvolle totstand-koming van het proefschrift.

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Sant Martina Labyrint, Lucca (Italië)

Latijnse inscriptie: "Dit is het labyrint dat de Kretenzer Daedalus bouwde en waaruit niemand die binnen was kon ontsnappen, met uitzondering van Theseus. Ook hem was het niet gelukt als Ariadne hem niet uit pure liefde met een draad had geholpen."

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Sant Martina Labyrinth, Lucca (Italy)

Latin inscription: "This is the labyrinth which the Cretan Daedalus constructed, out of which nobody could get who was inside, except Theseus. Nor could he have done it unless he had been helped by Ariadne's thread, all for love."

About the Author

Margrethe Kobes (1977) graduated from pre-university education at De Waezenburg in Leek (1995). She holds a Bachelor's degree in Building Engineering from Hanze University Groningen (1999) and a Master's degree in Science and Innovation Management from Utrecht University (2006). In her master thesis she discussed the policy aspects which apply to the implementation of Fire Safety Engineering in the Netherlands. In 2007 she started a part-time PhD project with the Crisislab, the research group around the program Crisis Management and Safety at the Department of Governance Studies of the Faculty of Social Sciences at VU University Amsterdam, in collaboration with the research department of NIFV and the Design Systems group of the Faculty of Architecture, Building and Planning at Eindhoven University of Technology. This publication resulted from the PhD project.

In 1999 she commenced her professional career as a building safety inspector at several municipal Fire Services. In the meantime she participated in research projects of *Nibra*, which is currently the Netherlands Institute for Safety (NIFV), an authoritative centre of competence in preparing professionals for incidents, crises and disasters. A few years later, in 2002, she joined the research department of NIFV with a fulltime research position. She has been involved in various research projects, for example in the evaluation study of a fire in Euroborg football stadium, several statistical studies on fatal domestic fires, studies on the safety of consumer products and studies on fire safety policy, such as on the use of simulation and calculation tools in building license requests in Dutch municipalities. As a lecturer she developed the course '*Human Behaviour in Fire*' in a curriculum for a Fire Safety Engineering program on Bachelor level and she trained many professionals in the subjects of fire investigation, human behaviour in fire and in the use of fire safety engineering methods, including in the use of the Fire Response Performance model. Moreover, she is member of the editorial staff of the Dutch scientific journal 'Tijdschrift voor Veiligheid' (Safety and Security Journal).

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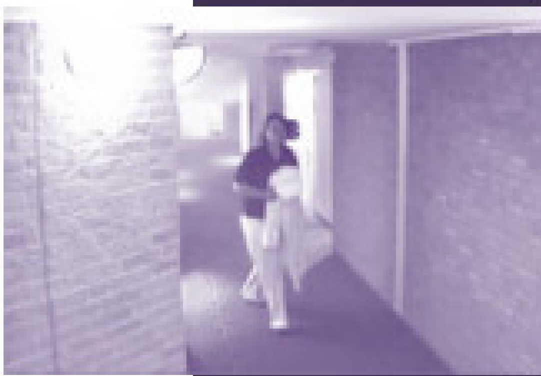
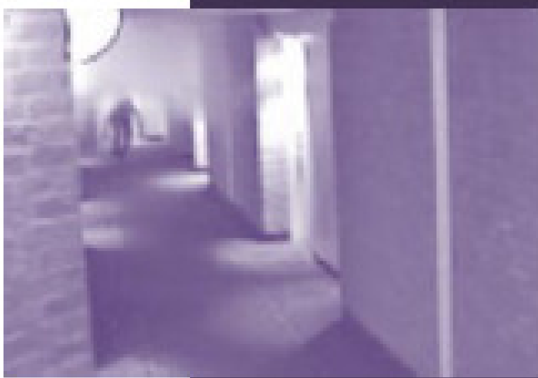
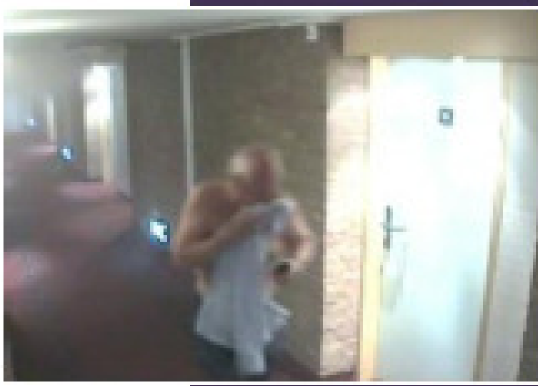
To provide policy measures for a safe escape in the event of a fire, clear and extensive knowledge about human behaviour in fire is essential. This implies a need for further knowledge of the interaction between surrounding factors (fire situation, building design, social factors) and occupants' fire response performance (FRP). A new research method has been developed to obtain the required insight into human behaviour in fire evacuation. The new research method consists of an analysis model (FRP model) and a virtual environment, the serious game ADMS-BART: the *Behavioural Assessment and Research Tool* (BART) in the *Advanced Disaster Management Simulator* (ADMS).



In this publication an introduction of the new research method is presented, as well as the results of the validation of the use of ADMS-BART as a research tool. Furthermore, an overview of existing literature on human behaviour is given. In addition, new findings on fire safety psychonomics are presented. The new findings are gained from a case study (football stadium fire, 2008) and from an experimental study in a real hotel, as well as in a virtual replica of the hotel. The studies were focussed on the influence of human factors, building factors and fire factors on fire response performance, and on the wayfinding performance in particular.





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